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NAVAL RESEARCH LABORATORY
REPORT

1 January 1942

GEIGER COUNTER TECHNIQUE

By Herbert Friedman

- Report H-1800 -

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NAVY DEPARTMENT

Report

on

Geiger Counter Technique

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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Appendix - (cont'd)

I. AUTHORIZATION

1. The work described in this report forms part of a program devoted to research on the application of Geiger-Muller counters to inspection with x-rays and gamma rays. The authorization is under the Bureau of Ships Project order 384/41. Refer to NRL letter N8-12 Radiography of September 23, 1940 (BuShips file No. NP14/N8(9-23).

II. INTRODUCTION

2. An investigation of the possibilities of utilizing Geiger-Muller counters for rapid inspection with penetrating radiations has been undertaken at the Naval Research Laboratory. Preliminary results, reported in NRL Report H-1799, indicate that the counter, even in its simplest form, is sufficiently sensitive to make its use more advantageous than the usual photographic techniques in many cases.

3. The Geiger-Muller counter, until recently, has found its major application in cosmic ray and nuclear physics. The intensities measured in such work are generally weak, producing counting rates of the order of hundreds per minute in average sized counters. There has been relatively little need for high speed counters and circuits. In radiography, however, the sources of radiation are very strong, producing intensities equivalent to counting rates of thousands per second. Ordinary counters, however, are much too slow to count that many random pulses per second without considerable loss. The use of counters as sensitive elements in devices for rapid inspection with intense X and gamma radiations, therefore, calls for extremely high resolution in both the counters and their associated electronic circuits.

4. To develop counters with ultimate sensitivity and capable of meeting the requirements of high speed counting, a comprehensive investigation of counters and counting circuits has been carried out at the Naval Research Laboratory. The more important results of this investigation may be listed as follows:

(A) New designs for gamma ray and hard x-ray counters have been developed, producing counters with quantum counting efficiencies up to 50%. Nowhere, in the literature, have any gamma ray counters been described with efficiencies greater than 2%. For soft x-ray counting efficiencies of 100% have been attained at the Naval Research Laboratory. The majority of soft x-ray counters built previously operated on a principle that did not permit greater than ten per cent efficiency.

(B) Resolving powers of up to 100,000 random counts per second have been achieved by a new principle of counter construction. Highest speeds have previously been obtained by use of Harper-Neher quenching circuits, and did not exceed 3000 counts per second.

(4) The process of preparing and filling counters has been studied with the intention of standardizing the technique involved. The essential procedure in preparing counters is now sufficiently well understood, that it is possible to produce good counters consistently.

(5) A variety of electronic circuits have been perfected for various special applications. These range from a very simple circuit for detection of peak intensities to very high speed scaling and frequency meter circuits.

5. To understand how the results listed under the first three headings were attained, it is necessary to have a very much more complete picture of the counting action than was presented in Report M-1799. The opening section of this report is therefore devoted to a theoretical analysis of the counting process, in which is discussed all those aspects essential to the understanding of the following sections. These latter sections are concerned with the construction and preparation of counters, and the methods of obtaining high resolution and high sensitivity. The final section of the report describes the most important circuits for counting and the conditions under which they are to be employed.

III. THEORY OF COUNTING ACTION

A. Point Counters

6. Counters were first designed by Rutherford and Geiger in 1908. In its original form the counter consisted of a pointed wire surrounded by and insulated from a metal cylinder. A potential difference of somewhere between 1500 and 5000 volts was applied across the counter and a high series resistance. In this early design,(1) the cylinder was made positive with respect to the wire. Figure (1a) illustrates the arrangement of electrodes and recording apparatus. The principle of operation may be briefly described as follows. An ion entering the counter is accelerated in the high field near the point, up to energies sufficient to produce large numbers of ions by collision, at the existing gas pressure. The ionization process is cumulative, the charge flow finally reaching a magnitude of about 10^{-8} coulomb, dependent, of course, on the potential difference and circuit constants. The collected charge causes the voltage across the counter to drop to a point where the discharge is quenched, and the counter then recovers by the leakage of charge through the resistance R. The voltage changes across R are indicated by the electroscope.

B. Proportional Counters

7. The above type of counter was later somewhat modified for use as a proportional counter (2). In the original counter, the primary ion acts as a trigger on the discharge, which once started, yields an effectively constant magnitude of charge before extinction. If a small metal ball is attached to the point and placed at positive high potential relative to the cylinder, instead of negative, then a range of voltage can be found in which the pulse is proportional to the original amount of ionization.

C. Geiger-Muller Tube Counters

8. The most important type of counter for measurements of x-ray and gamma ray intensities is the tube counter (Figure 1b) developed by Geiger and Muller (3) at about the same time as the proportional counter above. In the tube counter, the two electrodes are a cylindrical cathode and centered anode wire, insulated from each other. No current flows between the electrodes until some ion formation has occurred. If the potential difference applied to the electrodes is sufficiently high, the multiplicative process of ionization by collision takes place, as the original ion creates others in its acceleration toward the anode. With increasing potential difference across the electrodes, the amplification of charge increases until the condition of self-sustained discharge is attained. If the counter is properly constructed and filled and the correct potential difference chosen, it may be effectively self-quenching. If it is not self-quenching, circuits have been designed which will quench the discharge quickly, after it has once started.

9. Before going any further it is well to study the relation of the characteristic G. M. counter region to the general voltage-current curve for such an electrode arrangement. Suppose some ion pairs are formed in the interelectrode space. The quantity of charge collected by the wire is illustrated schematically in figure (2). The two curves drawn, indicate charge collected by the wire for two different quantities of initial ionization due to the incident radiation. The lower curve may be taken to represent the formation of a single electron-ion pair, and the upper curve, a very large number of initially formed ion pairs (such as might result from an alpha particle). At the lower portions of the curves, region A, recombination is very efficient and little charge reaches the collecting wire. With increasing potential, in region B, saturation is attained. All the charge arrives at the wire, but the electrons still have insufficient energy to produce ionization by collision. In region C, electrons receive sufficient acceleration to start electron avalanches by collision. In this range both curves are parallel indicating proportional amplification. This is the region in which proportional counters are operated. With further increase in potential difference, the curves approach each other in region D, which represents the foot of the non-proportional amplification range and the beginning of what is termed the Geiger-Muller region. Region E covers a range of potential difference in which the total amount of ionization is independent of the intial amount. This is the Geiger-Muller range.

10. In the counter as originally applied, the current pulses lowered the wire potential sufficiently for detection and the charge accumulated in each pulse leaked off through a very high resistance in series with the counter and voltage supply. Referring to figure (2) again, the portion D + E may be called the region of non self-sustaining discharge (the IR drop in the large resistor is sufficient to extinguish the discharge). Experimentally it was found that the length of plateau was proportional to R. With decreasing R, the plateau vanished and the condition of self-sustained discharge follows region D with no evidence of a plateau. This may be expressed by the equation:

$$V_{Dis} - V_{min.} = \text{constant} \qquad (1)$$

11. The constant must be a current i. If R is taken as 10^9 ohms, equation (1) indicates a steady current through the counter of up to 10^{-7} to 10^{-6} amperes.

12. If the initial potential is somewhere between V_{Dis} and $V_{min.}$, the pulse size will be given by the drop from V_i to somewhere slightly below $V_{min.}$ Figure (3) illustrates the voltage on the wire as a function of the time from the triggering of the discharge. For a leak resistance of 10^9 ohms and a counter about 10 cms. by 2 cms, with 20 mil wire, $t_{RC} + t_{dis}$ is about 10^{-2} seconds, which we may call the resolving time of the counter. The resolving time may be decreased by decreasing R, but then the plateau vanishes. Obviously, such a counter cannot be used at rates much greater than ten per second, and falls into a class known as slow counters. In contrast, it is now possible to make fast counters for which the breakdown plus recovery time lies between 10^{-5} and 10^{-4} seconds.

13. Figure (3) is an oversimplified picture of the breakdown-recovery process and it is worth considering the action in greater detail in order to determine what factors enter into the design of a fast counter. Suppose again, that an ion pair is formed between the electrodes in the region E of figure (2). The electron is accelerated toward the wire while the positive ion moves slowly toward the cathode. In the neighborhood of the wire, the electric intensity increases rapidly and it is there that the electron gains sufficient energy to excite and then ionize a gaseous atom. The electron that it ejects in this region of intense field is in turn accelerated and produces still more electrons by collision with gaseous atoms or molecules. This cumulative process of electron production and motion toward the wire is called a Townsend avalanche. Nothing has been said previously about what happens to the positive ions during the production of the avalanche. A positive ion has a mobility very different from that of an electron. The field strength necessary to give a positive ion unit acceleration is almost 2000 times that required to accelerate the electron. During the interval that is required for development of the electron avalanche, then, it is safe to assume that there is almost negligible motion of the positive ions, and a relatively stationary positive space charge is built up in the vicinity of the wire. The ionizations that occur in the avalanche process are accompanied by the emission of light, and the photons in turn are capable of ejecting more electrons from the cathode surface. These photoelectrons can then trigger further avalanches and the whole succession of events may repeat itself many times as a consequence of the action of the primary electron.

14. Thus far, it would seem that the electronic avalanches could build up indefinitely. Simultaneously, however, the positive space charge has grown as rapidly as the number of avalanche electrons. The stage is soon reached where the positive charge around the wire is so great that the diameter of the wire is effectively extended far out into the inter-electrode space. The intense accelerating field is then no longer existent and the process of electron multiplication and associated photon emission is discontinued. To sum up, then, the original ion pair is multiplied many orders of magnitude, the electrons produced in successive avalanches rush

to the wire, the positive ions create an almost stationary space charge, and the discharge is completed in a time of the order of 1/10 to 1/100 microsecond. Almost the entire process of electron multiplication has occurred close to the wire and the total charge displacement is consequently very small. As a result, the potential of the wire changes hardly at all in spite of the fact that a hundred million or more electrons have been collected. The major portion of the potential change of the wire occurs after the quenching of the discharge as the positive ion sheath drifts to the cathode.

15. The action of the space charge on the field strength between the electrodes is illustrated qualitatively by figure (4). Initially, the field is represented by curve (a), i.e., it varies inversely with the distance from the wire. The potential of the wire with respect to the cathode is the integral of the field strength across the space between the electrodes or simply the area under curve(a). Curve (b) represents conditions immediately after quenching the discharge. The amount of charge that has flown has produced a negligible change in potential and the integrated area under the curve is almost the same as in (a). The space charge, however, has effectively increased the wire radius to r_0 and the field strength between R - wire and R - cathode is too small to produce multiplicative ionization. Curve (c) is for a time shortly after quenching. The sheath of positive ions has drifted appreciably toward the cathode and the total area under the curve has begun to decrease, representing the drop in potential difference accompanying the motion of positive ions toward the cathode. Curve (d) represents the condition, where most of the charge has been collected, and the area between (a) and (d) represents the accompanying change in potential of the wire.

16. In the above discussion, it was shown that the entire discharge takes place in a period of from 10^{-7} to 10^{-8} seconds. If that completed the counting process all counters would be fast. The differences in speeds of counters, arise from the remainder of the counting action. Returning to the stage where the positive ion sheath arrives at the cathode, it appears that the completion of the counting action is determined by what results from the bombardment of the cathode by the positive ions. To begin with, consider the simplest case. Suppose these positive ions eject no secondary electrons from the cathode. They are then simply neutralized by electrons drawn from the cathode surface, while the electronic charge collected by the wire leaks off through the external resistance, allowing the counter to return to its original state. Actually, the above condition seems to be attained by the addition of a small amount of organic vapor to the gas in the counter. In some way, this vapor must affect the cathode surface so as to greatly decrease the probability of electron emission by positive ion bombardment. Argon-Alcohol counters may be used effectively with leak resistences of only 10^5 ohms, and in some cases even as low as 5000 ohms. Since the discharge is completed in 10^{-7} to 10^{-8} seconds and since the space charge may be swept out in 10^{-5} seconds, the recovery time of these counters is effectively given by the product RC of the leak resistance and the capacity, which is generally of the order of 10^{-4} seconds. The shape of the voltage pulse is given in (a) of figure (5). Alcohol counters are generally called self-quenched but the discharge is effectively quenched before the alcohol has acted. The function of the alcohol is to prevent reignition of the discharge.

17. Now take the case where the efficiency of production of secondary electrons by positive bombardment is high. In the initial discharge, if the leakage resistance is high, if the capacity of the wire system is small, and if the number of positive ions is large, the resulting change in potential of the wire due to the migration of positive ions toward the cathode may be large enough to produce "overshooting". Under these conditions, the change of potential may drop the counter below the Geiger-Muller region by the time the positive ions reach the cathode. The secondary electrons from the cylinder well then find the existing field in the vicinity of the wire insufficiently high to accelerate them to energies required for production of Townsend avalanches. As a result there is no multiplication of this secondary charge and no further decrease of wire potential following the initial discharge. The critical potential below which the wire must fall to prevent reignition is slightly less than the threshold voltage. If the leak resistance is of the order of 10^9 ohms, the above conditions will generally hold. If, however, the leak resistance is lowered, or the capacity of the wire system increased, a third mode of counting is observed.

18. Suppose the wire potential does not fall below the above mentioned critical potential in the first discharge. The secondary electrons from the wall then find the accelerating field near the wire sufficient to produce Townsend avalanches again and a second discharge takes place. The second positive ion sheath moves toward the cathode with further reduction of the wire potential, and may reach the cathode with the wire potential still above the critical voltage, so that a third discharge takes place. Each successive ion sheath will carry less charge because the wire potential is lower after each discharge. The wire potential assymptotically approaches the critical voltage in an irregular way until the number of electrons released in the nth breakdown is so few that a statistical fluctuation to zero secondary emission will break the chain of discharges. Typical pulses of this type are illustrated in (b) and (c) of figure (5).

19. The above discussion might seem to indicate that fast counters must necessarily be of the vapor type. This is not true. Almost any counter may be made to behave like a fast counter with suitable electrical circuits. A counter which normally falls into the 2nd or 3rd class discussed above, may be supplied with an electrical quench circuit which will "overshoot" the voltage on the 1st discharge even when the leak resistance is dropped to 10^6 or 10^5 ohms. Such circuits will be described later.

IV. <u>CONSTRUCTION OF COUNTERS</u>

20. A large volume of material has been published on the technique of constructing and filling Geiger counters. Examination of these papers reveals a wide range of differences between techniques employed by various authors. The reaction of a newcomer to the field of counter research is that counters are very tricky gadgets, unstable, and difficult to construct properly, and the tendency is to conclude that the production of a good counter is a hit or miss process. In reality, the construction of a good counter can be carried out with almost complete certainty. The development of counter technique has progressed beyond the trial and error stage that produced the above mentioned variety of formulas, to where the fundamental requisites of a good counter are quite well understood.

21. To begin with, all counters may be placed in either of two classifications, non-vapor and vapor type counters. The former type involve the greater care in preparation and require sealed glass envelopes to allow for proper treatment. The vapor type counters are much less critical in their preparation and permit a variety of materials and modes of design in their construction.

A. Preparation and Filling of Counters

22. A general purpose filling system was built, and is sketched diagrammatically in Figure (6). The fore-pump is a Cenco Hyvac and is backed by a single stage oil diffusion pump. The mercury well is employed as a pump and mixing chamber, providing a means of thoroughly mixing the gases and vapors before sealing off the counters. Additional traps may be included in the system when expensive rare gases are used, to prevent their loss.

23. Having constructed a counter and arrived at the stage of preparing it to be filled, the following procedure should be adhered to for non-vapor type counters.

(1) Clean thoroughly with acid and then rinse many times with distilled water. (Insufficient cleansing shows up after baking in discolorations produced by CuO and Cu_2O.)

(2) Pump the counter down to a high vacuum of the order of 10^{-5} mm.

(3) While still on the pump system, the counter should be baked for about two hours at about 400° C., to thoroughly outgas the metal cylinder.

From this point on the procedure is determined by the type of gas to be used for filling the counter. Consider separately the method for (a) hydrogen or a mixture of hydrogen and a noble gas, and (b) oxygen or air.

(4) (a) At the conclusion of step (3) the cylinder is covered with a thin dark layer of copper oxide. It is essential to remove this layer if the counter is to be filled with hydrogen or a mixture of hydrogen and a noble gas. The cylinder must look bright. (A bright cylinder will show the individual crystallites with characteristic glitter.) This is accomplished by admitting commercial hydrogen up to a pressure of about one atmosphere and baking until the copper is reduced.

(b) If oxygen or air is to constitute the counter filling, the oxide coating left from step (3) is desirable. By baking in an oxygen atmosphere the tendency is to obtain a flaky coating as soon as the oxide surface becomes appreciably thick. If the oxidation is slow (carried out at low temperature) a greyish surface is attained. For best results the surface should have a velvety black color. Such a surface may be obtained by the following method.

The brass or copper should first be washed with a 50% nitric acid solution. This solution attacks the metal vigorously. Upon removal of the acid, the metal must be rinsed very quickly with water and then with alcohol. The result is a bright unoxidized surface. The next step is a thorough drying on the aspirator, followed by filling the counter with nitric oxide to over-pressure. When baked for from twenty minutes to one hour at 275°–300° C. in this NO_2 atmosphere, the metal becomes coated with a soft, velvety black surface--not grey and not blistered. While still warm, the counter should be pumped dry on the aspirator, followed by the Hyvac for about 20 minutes.

The nitric oxide necessary for proper oxidation of the cylinders may be prepared simply, as follows. Lead nitrate is distributed along the length of a glass tube about 18" long, which connects to a large bulb. The nitrate is preheated for about 30 minutes at 300° C., while the system is pumped continuously by the aspirator. (The tube containing the nitrate is plugged with glass wool at the end leading to the bulb). The temperature is then raised to from 370° C. to 400° C. and the NO_2 that is evolved diffuses through the glass wool and condenses in the adjoining bulb, which is cooled with a dry ice mixture.

(5) Pump the counter to high vacuum and outgas the wire by heating to incandescence (about 2200° C.). A volume of gas 4 to 5 times the volume of the wire consisting mostly of CO is given off. The wire should be heated on and off for a period of about half a minute.

The above step is recommended but is not very important. There is some tendency to reduce spurious counts, as evidenced by a lower background counting rate, and this effect may be attributed to the removal of sharp cracks and points formed by oxide scale on the wire.

We have found that electrolytic polishing of the wire gives a more pronounced reduction of spurious counts. The polishing is accomplished very simply by filling the assembled counter with .025 normal solution of potassium hydroxide and passing a current of about 50 ma. per square centimeter of wire surface, through the solution. The polishing requires from twenty to thirty minutes.

(6) Before filling, while the counter is still being pumped, a dry ice mixture should be placed around the trap. It is not meant to remove mercury vapor, which is apparently harmless, but does help to remove harmful organic vapors, and water vapor. The latter affects the insulation.

(7) Fill with suitable gas mixture. The type of gas filling that is chosen determines threshold voltage, efficiency and discharge time. The set of curves figures (7-13) due to C. L. Haines[4] illustrate pretty well the effects of different gas mixtures on the threshold potentials of non-vapor counters. The 90% argon plus 10% hydrogen mixture is particularly efficient and has a much lower threshold than argon-oxygen, which also works well. A pure noble gas yields almost no plateau because it tends toward the formation of metastable states, which in turn produce high probability of secondary electron emission from the cathode. The addition of air, hydrogen, or oxygen, tends to quench these metastable states through inelastic collisions. Pure oxygen makes a poor counter because of its high electron affinity, leading to the capture of electrons with high probability. Air is unsatisfactory because N_2 and O_2 react chemically in the discharge process.

24. Hydrogen filled counters exhibit the greatest lengths of plateau and the greatest stability. In filling, electrolytically produced hydrogen should be admitted to the counter by diffusion through a palladium tip. The tip (Plate 11) is a cylinder 1-1/2 inches long by 1/8 inch in diameter, closed at one end. The other end is welded to a platinum cylinder which is sealed to a soft glass to pyrex graded seal. The palladium tip is surrounded by a nichrome spiral heater. Impure hydrogen, admitted through the intake side, diffuses through the heated palladium wall very readily, while other gases are totally excluded.

25. The preparation and filling of vapor type counters is much less critical than the procedure prescribed above for non-vapor counters. A much wider choice of materials is permissible and the baking treatments may be dispensed with, both factors lending much greater flexibility to the design, and ease of construction.

26. A variety of materials may be used in the construction of vapor counters. Almost any metal will serve as cathode material, but oxidized copper and brass have given best results. The wide choice of cathode metals makes possible many unusual designs. Counter (d) plate (29) is simply a kovar cylinder with glass end plugs fused on. The anodes may be made of tungsten, piano wire, copper, and many other metals. Wires may be centered through bakelite or mica disks plugged in the ends of the cylinders. Transparent bakelite is recommended. Glass envelopes may be replaced with metal shells, and sealing materials like glyptal and picein have no noticeably bad effects. Counters (b) and (c) plate (29) are mounted on standard radio tube bases. In the photographs, they are shown with glass jackets piceined onto the base. These glass jackets may be replaced by metal shells, welded or soldered to the base.

27. The action of vapor counters has already been described. The best gas mixtures are combinations of a rare gas with a trace of alcohol, or petroleum ether. It is desirable to oxidize the cathodes as described above, but the vigorous cleansings are unnecessary. It suffices to simply wash with alcohol. The alcohol vapor that is used in the final gas filling should be freed of water vapor by passing through calcium oxide. The characteristics of some of the alcohol-argon counters built at the Naval Research

Laboratory are plotted in the curves of figures (16, 17, 18, 19 and 20). The effects of varying the argon pressure, vapor pressure, and dimensions and material of cathode, may all be obtained from these curves.

28. The best counters of the vapor type are those filled with argon and petroleum ether. A comparison, figure 20, of the characteristic curves of geometrically identical counters filled with either alcohol or petroleum ether, indicates clearly the advantage of using petroleum ether. The plateau region is more than twice as long and the counter using petroleum ether may be carried more than 500 volts above threshold without going into a condition of self-sustained discharge.

29. The simple system shown in plate (12) was built for filling counters of the petroleum ether type. The trap is included to prevent ether from reaching the Hyvac pump. The counter itself is connected to the system with rubber tubing. The system, after first being pumped down, is filled to over-pressure with Argon. The counter is then pulled off the rubber tubing a few drops of ether are squirted in with a medicine dropper, and the rubber tube is quickly slipped back over the counter pump-off tubing. All this must be done as quickly as possible. The counter is then pumped down to about 6" total pressure, is allowed to remain at that pressure a while, and then is filled with Argon to atmospheric pressure. This process is repeated a few times, after which the counter is tested. If it does not work at this stage, the alternate pumping and filling is repeated until it does.

30. The method described above has produced the best counters. In attempting to standardise the procedure, it has been found that a mixture of one inch of petroleum ether pressure to one atmosphere of Argon, may be depended upon to yield fairly good counters. With large counters, it is generally observed that the counters will not begin to count well until a few hours have elapsed after filling.

B. Testing Counters

31. The most important tool in counter testing is the cathode-ray oscilloscope. It affords a direct means of observing the pulse shape and therefore indicates immediately whether there is a tendency towards multiple counting. Plates (31, 32, and 33) are included to demonstrate the use of the oscilloscope in studying counter action. The six oscillograms of plate (31) illustrate the types of pulses in a counter filled with pure argon at various pressures.(5) Obviously, there is a strong dependence of pulse form on pressure. At the lowest pressure, the pulses are very long and not very high. Increasing pressure increases the pulse height, but also increases its length. The pulses are not simply shaped as in figure 3, but are of a multiple type. At higher pressure, the secondary pulses attached to the initial pulse, become further and further separated and begin to register as separate counts in the recording apparatus. In the last case illustrated, a pressure is reached where the counter no longer recovers. The plateau has vanished.

32. Plate (32) illustrates the effect of adding alcohol to the argon. The oscillograms indicate increasing pulse size with increasing alcohol pressure, but now the increase is confined to the initial breakdown,

with the result that the pulse length is greatly decreased. With sufficiently high alcohol content, the secondary pulses disappear entirely and the counting action is reduced to a single short pulse.

33. The effect on pulse shape, of varying the series resistance, is shown in Plate (33), for a good argon-alcohol counter. The pulse is greatly sharpened by reduction of the series resistance.

34. In figure (32) plate (32) a type of multiple count is shown that occurs even when good alcohol pressure is present. The effect is observed near the upper part of the plateau and sets a limit on the usable length of plateau. It has been traced to the presence of slight amounts of air as impurity in the argon.

35. The above examples give ample evidence that the oscilloscope is an indispensible tool in studying counter action. With the oscilloscope, it is also possible to measure resolving times of counters, but the simplest method of doing this is to use a high speed scaling circuit. In almost all cases, these circuits can be built with greater resolving powers than the G.M. counters. It is then possible to determine the resolving time of the counter directly from its maximum counting rate, measured with the scaling circuit.

36. As a final test, all removable sources of radiation should be carried as far from the counter as possible and determination of the "background" counting rate then made. A certain number of counts per minute are to be expected purely from cosmic radiation and radioactive contaminations in the metal parts. This number depends upon the geometry of the counter. For a tube counter ten centimeters long by two centimeters in diameter, a background of fifty to sixty counts per minute may be expected. A "background" counting rate greater than this is an indication of spontaneous counts. These spurious counts result from improper cleansing and the presence of sharp points on the electrodes. Improper cleansing may leave spots of non-conducting coating on the electrodes and these spots become electron emitters under the influence of the high field strengths at the non-conducting points. They not only affect the background rate, but increase the shape of the plateau and decrease its length.

V. EFFICIENCY AND RESOLUTION OF COUNTERS

A. Conversion of X-Rays and Gamma Rays into Ionization Products

37. The interaction of x-rays or gamma rays with matter may result in the liberation of photoelectrons, Compton scattering, and pair production. For x-rays of energy less than 70 kv, practically all the absorption is photo-electric in character. That is to say, the x-rays impinging on the atoms of the absorber, convert their energies into kinetic energy of ejected electrons. With increasing kilovoltage, the photoelectric absorption diminishes rapidly, and the scattering effect gains in importance. One may picture this scattering as a sort of diffusion of x-ray photons through the electron clouds making up most of the volume of the absorber. A portion of the energy of the primary radiation goes into recoil motion of the scattering electrons. The remainder appears in the form of softer

x-rays in all directions, and is absorbed quickly. In the region from 200 kv to 1000 kv, the recoil electrons may take from 10% to 40% of the primary energy. This energy is then further dissipated in ionization by collision. Above 1,000 kv, a new process appears, called pair production, which is similar to a photoelectric effect. It is the conversion of the energy of the primary x-ray on gamma ray into a positron (positive electron) -- negatron (negative electron) pair. The majority of these pairs are reconverted into hard radiation by recombination. The process of pair formation is most probable at high energies and for heavy materials. All three interaction processes convert x-ray or gamma ray energy into kinetic energy of charged secondary particles.

3. Design of Gamma Ray Counters

38. Instruments designed to indicate x-ray intensities, such as for example, ionization chambers, Geiger-Muller counters and cloud chambers are sensitive, not to the primary radiation, but to the secondary electrons. Since almost all gamma ray absorption is by Compton Scattering, the radiation is absorbed almost entirely in the metal wall of the detector. It is apparent then that the efficiency of the gamma ray detector is determined by the dependence of the emergent intensity of secondary radiation on the thickness of material within which it is produced.

39. Consider the process of gamma rays being detected by a Geiger-Muller counter. Suppose the primary gamma radiation to have an absorption coefficient μ_1 in the metal cathode material, and furthermore, let it be assumed that the secondary β radiation produced is also absorbed exponentially with a coefficient μ_2 (where $\mu_2 > \mu_1$). As a further simplification consider the secondary radiation to be emitted in the direction of the primary radiation.

40. Let t be the thickness of the counter wall. At a depth x, the transmitted intensity will be

$$I_x = I_0 e^{-\mu_1 x} \qquad (1)$$

where I is the incident primary intensity. Between x and x + dx the amount absorbed will be

$$\mu_1 I_x d_x = \mu_1 I_0 e^{-\mu_1 x} d_x \qquad (2)$$

41. Now, if it is assumed that the absorption of each primary quantum results in a secondary β particle with momentum in the same direction, then equation (2) also gives the number of secondary corpuscles emitted in the x direction. After the electrons have traversed the residual thickness of counter wall, only

$$(\mu_1 I_0 e^{-\mu_1 x}) \; e^{-\mu_2 (t - x)} \, dx \qquad (3)$$

will emerge. (t = thickness of cathode wall)

42. When expression (3) is integrated over the total thickness of counter wall, we find that I_2, the intensity of emergent secondary radiation is given by

$$I_2 = I_0 \frac{\mu_1}{\mu_2 - \mu_1} \left[e^{-\mu_1 t} - e^{-\mu_2 t} \right] \qquad (4)$$

43. Figure (27) shows the variation of I_2 with thickness of counter wall t. I_2 increases at first with increasing thickness, reaches a maximum and then falls off slowly. The second exponential factor decreases at a much slower rate than the first so that after a sufficient thickness has been traversed the second exponential is negligible compared to the first. The secondary radiation then decreases with the coefficient μ_1, of the primary radiation, while the composition of the emergent radiation becomes constant. At equilibrium, the ratio of the intensities of the secondary and primary radiation becomes

$$\frac{\mu_1}{\mu_2 - \mu_1}$$

44. It can be seen therefore that the efficiency of the counter for detection of γ-rays is approximately given by the ratio of μ_1 to μ_2, for $\mu_2 \gg \mu_1$. The curve of figure (22) indicates a maximum efficiency for Al when the wall thickness is 5 mm. For Cu equation (4) indicates maximum efficiency for about 0.2 mm. cathode wall.

45. From the above, it would appear that, to increase the number of secondary electrons per unit of cathode area, it would only be necessary to go to heavier elements since μ_1 increases more rapidly than μ_2 with atomic weight. Evans and Mugele[7] have tested various types of metal cathodes and find that lead is 1.3 times as efficient as copper.

46. Further gains in efficiency may be accomplished by increasing the exposed surface area per nominal square centimeter of cathode. The exposed inner surface may be increased by a factor of $\sqrt{2}$ over that of a smooth cylinder by cutting 45° threads on the inside, or by a factor of $\pi/2$ by employing a closely wound helix of 16 or 20 gauge wire as the cathode.

47. The greatest advantage is gained by the use of screen gauze cathodes. It has been shown that most of the exposed surface of every wire of the mesh is effective in giving secondary electrons. The electric field seems to penetrate the mesh to an extent sufficient to draw in electrons ejected from the exterior of the cathode. Figure (23) from the above reference shows the relative surface area and relative sensitivity of a smooth, cylindrical, solid, and 20, 60 and 100 mesh copper cathodes.

C. Methods for Increasing Resolving Power and Efficiency of Vapor Counters.

48. Before going any deeper into the problem of increasing the quantum efficiency of a counter for γ-rays, consider more carefully the factors that control the resolving power of a counter. High resolution, as well as high quantum efficiency, is essential for ultimate sensitivity.

49. If one observes the discharge pulses of an argon-alcohol counter as indicated on the oscilloscope, a number of pulses smaller than the normal size may be seen. Suppose the counter is in a condition somewhere between (c) and (d) of figure (4). The discharge has been quenched but the space

charge has not yet been completely swept out by the field. At this point, let us suppose that a quantum of radiation ejects a photoelectron and initiates a new discharge. These newly formed avalanche electrons find a much smaller accelerating field close to the wire and only a small amount of newly formed positive ions is required to bring the positive ion sheath, already available, back to the size necessary to quench the new discharge. The resulting pulse is consequently small. If the new discharge is initiated between (b) and (c) of figure (4) the field is probably too weak to produce any ionization by collision and the counter does not respond to the quantum of radiation. Between (b) and (d) various sized pulses may be produced. The time between a discharge and the closest next succeeding one that can produce a pulse large enough for the amplifier to record, is called the resolving time of the counter. For an argon-alcohol counter about ten centimeters long by two centimeters in diameter with ten mil wire and a tenth megohm leak resistance, the resolving time will be of the order of 10^{-4} seconds. Similar non-vapor counters can be made to count as fast by employing an electrical quench circuit.

50. With a resolving power of 10^{-4} seconds one may count up to 1000 counts per second with fairly good proportionality. The loss at the maximum rate will be about 10%. For a one second measurement the mean fluctuation due to randomness would be 3% and to obtain a one per cent mean error the measurement would require ten seconds. To be able to measure intensities to 1% in one second requires that we increase the resolution by a factor of ten.

51. For argon-alcohol counters, this gain in resolution may be obtained as follows. Suppose two similar counters are connected in parallel. From figure (16) it is apparent that the pulse size in an alcohol counter is considerably smaller than the over-voltage. Because of this, one of the counters may discharge without affecting the sensitivity of the second counter. Accordingly, while the first counter is in its insensitive state, the second may still respond. The resolving time of the combination should therefore be half that of a single tube counter of equivalent volume. To test this, the counter shown in Plate (26) was built. It consists of a bundle of seven cylinders, each 5 cms. long by 0.5 cms. in diameter. The resolving power of this arrangement was found to be approximately fifteen times that of a single cylinder having the over-all dimensions of the bundle. It can count as many as 100,000 random counts per second. This extra large gain in resolution may be understood from what has been said about the discharge mechanism. In a smaller counter, the positive ions are carried away faster by the higher average field, giving a decreased resolving time. To sum up then, the substitution of a bundle of seven small counters for a single large one, increases the resolving power by a factor of seven due to the parallel arrangement, and by about another factor of two due to the greater capacity of the smaller diameter counters. Independently of the gain in resolution, the above design has also increased the effective cathode area, and therefore the gamma ray sensitivity, by a factor of 7/3 over that of the single counter of equivalent volume.

52. The principle of combining counters in parallel has resulted in a variety of designs. For most of our applications we are interested in measuring a collimated beam. Counters (J, K, L) of plate (27) are designed for such a purpose. The sensitivity is increased in proportion to

the number of cylinders traversed by the beam of radiation. With 100 mesh brass gauze cylinders, counter (L) plate (27) has an efficiency of 20% for detection of a collimated beam of gamma rays.

53. For beams of wider cross-section great sensitivity may be obtained by going over to a wire and plate arrangement of electrodes rather than a wire and tube. It should be remembered that the counting action is produced by the field in the neighborhood of the wire. The shape of the cathode is only of secondary importance. Figure 24 (a) illustrates the simplest arrangement of a single wire and plate. Figure 24 (b) shows a parallel extension of the wire and plate arrangement, and Figure 24 (c) a still further development, expanding the plate area and the number of wires. By building up a large number of decks, the quantum efficiency of such arrangements may be developed to as high as 50%. Figure 26 is a radiograph of a multiple plate counter built by the Texas Company, having seven decks with two wires per deck. The efficiency of this counter is five times that of a normal counter of equivalent volume. The large capacity of the wire system makes the pulse size for such counters very small, and high amplification of the pulses is required for recording.

54. Figure 27 illustrates another type of counter design. By stacking up many plates with many holes, greater gains in efficiency may be attained than by the multiple deck method.

D. Soft X-Ray Counters

55. The discussion thus far has been concerned with the construction of counters for gamma ray measurements. The design of counters for X-ray radiations above 0.1 Å involves entirely different considerations. The wave length range ordinarily covered in X-ray diffraction work is from 0.5 to 2.5 Å. In this range, it is possible to construct counters having practically 100% quantum counting efficiency. Figure 28 and Plate 28 illustrate the design we have employed for such counters. For the wave lengths we are considering, radiation passing through a heavy gas is strongly absorbed photoelectrically, and each quantum absorbed in the gaseous volume of a counter may be expected to initiate a count. By filling with heavy gases like xenon and krypton, counters may be made to cover the diffraction range with 100% efficiency at almost any wave length in the range. This is evident from Figure (30) which represents the absorption in a counter ten centimeters long as a function of wavelength and gas pressure. Most attempts(6) to utilize counters in the x-ray region have resorted to the photoeffect on the cathode wall, rather than gaseous absorption, to produce the triggering electrons. Tests at N.R.L. have indicated less than 10% quantum efficiency for such counters.

E. Hard X-Ray Counters

56. With increasing K.V. applied to the X-ray tube, the radiation becomes harder and the absorption by scattering increases. To bridge the gap between 0.5 Å and the x-ray region, counters have been made which combine some of the desirable properties of both the X-ray and x-ray type counters. Counter (L) of Plate (27) has a thin walled glass window and a 1 cm. aperture in the dural block, that allows radiation to pass down through the series of mesh cathodes. This arrangement combines a maximum amount of surface for photoeffect with large gas path.

VI. CIRCUITS FOR INDICATING COUNTING RATES

A. Requirements of High Speed Counting

57. There are two methods for indicating intensities as registered by a G. M. counter. The sum of the individual counts may be totalled on an impulse counter or the counter pulses may be fed into an electrical tank circuit with a current meter to indicate directly the extent to which the tank is charged. Both methods require equivalent resolution of pulses for the same counting rates.

58. Most of the counting circuits that have been described were designed for cosmic ray work. The intensities to be measured were generally of the order of a few hundred per minute and accordingly there is comparatively little published concerning counting circuits for rates in the neighborhood of thousands per second. The difficulties involved in designing circuits for these high speeds of counting can readily be appreciated when one remembers that the counting is random. It is not sufficient to obtain a circuit capable of counting a few thousand per second of regularly spaced pulses. Such a circuit would fail badly for random counting. There are large fluctuations in the intervals between pulses of a random distribution such as is obtained from radium radiation. Furthermore, the shortest time intervals are the most probable. So that even at low counting rates many pulses are too close to be resolved. For example, a mechanical counter capable of counting 100 periodic pulses per second misses almost 10% at only 10 random pulses per second. Obviously, exceptionally high speed circuits are necessary.

B. Quenching Circuits

59. The first problem in obtaining high speed counting is to cut down the resolving time of the counter itself to the desired value. For non-vapor counters, this is accomplished by the use of electrical quenching circuits. For coincidence counting in cosmic ray work, two circuits have been designed to speed the counter action by quenching the discharges quickly even with resistances as low as one megohm in series with the counter.

60. The first of these circuits is the Neher Harper[8] circuit, figure (33). Its operation may be analyzed as follows: With the bias on the vacuum tube adjusted for very little plate current flow, the resistance of the tube is high and the full high voltage is then across both the tube and counter. When the counter breaks down due to the passage of an ionizing particle, the positive charge collected by the cylinder raises the grid potential. The resistance of the vacuum tube then drops rapidly and current flows through R_2. When the IR drop in R_2 becomes large enough, the counter discharge is extinguished. The recovery is very fast because of the low resistance and capacitance.

61. In practice, the value of the grid potential E_g must be carefully chosen within certain limits. If E_g is made too negative the voltage impulse in R_g due to discharge of the counter will not be able to raise the plate current by an amount sufficient to cause extinction of the discharge. The counter is then insensitive to ionizing particles. As

the negative grid bias is raised, the point is soon reached where this "blocking" action occurs intermittently. When the negative grid bias is too low, the increased plate current may bring the counter too close to threshold and possibly below it. Close to threshold, the loss in counting efficiency is very noticeable.

62. The characteristic curves of a counter employed with the Neher-Harper circuit, are shown in figure (35) as a function of grid resistance. Figure (36) shows the relation of grid voltage to grid resistance, and figure (37) shows the counting rate linearity response of the circuit.

63. Some of the arguments against the Neher-Harper circuit are (1) its characteristics are sensitive to slight changes in grid bias, (2) the cylinder is at high impedance above ground and requires careful shielding, and (3) the capacity of the cylinder introduces longer recovery times for large counters.

64. The Neher-Pickering circuit[9] figure (34) is designed to eliminate these objections. The circuit diagram shows that no grid bias is required, the cylinder is grounded and the grid of the vacuum tube is connected to the counter wire. Since the grid is at zero potential in the absence of a pulse, the tube is normally highly conducting and represents a low resistance in series with the cathode resistor. Therefore, the cathode, screen voltage supply, and grid resistance are all at high potential above ground. This sets the counter wire, which is connected to the grid, also at high voltage. If an ionising particle now enters the counter, the grid bias goes negative, blocking the current in the tube. The resistance of the tube rises rapidly while the grid, screen, and cathode drop toward ground potential. When the counter potential falls below threshold, the discharge is quenched and the grid recovers quickly through the grid resistor.

65. Some disadvantages of the circuit are that an insulated heater supply is required and that the high voltage supply must stand a constant current drain of about a milliampere.

66. Other quenching circuits are described under uniform pulse generators below. With vapor counters, the method of obtaining high resolution by parallel arrangements has already been described. No special quenching circuits are needed.

C. Scaling Circuits

67. After having achieved high resolution in the G. M. counter, the next problem is to find a means of counting the G. M. counter pulses without loss. This requires a circuit with resolution at least equal to that of the counter. Since impulse counters, such as the popular Cenco counter have resolving times of the order of about 0.01 second, it is necessary to scale down the number of pulses received from the counter by a large factor, when counting at a high rate. A scale of 100 circuit, for example, would feed the mechanical counter only 10 pulses for every 1000 counter pulses.

68. The earliest scale circuits were the Wynn Williams thyratron ring circuits published in 1931. They were simply a series of thyratrons connected in a ring in such a fashion that when an input pulse fired one of the thyratrons, it thereby prepared the next thyratron in the ring to fire on the succeeding pulse. If N thyratrons were included in the ring, each tube would fire once for N pulses.

69. The ring circuits were superceded by the scale of two type of circuit. Such circuits furnish one output pulse for each two input pulses. With n successive stages in series a scaling ratio of $2^n = N$ is obtained. Each elementary scale of two units is an extremely fast electronic switch or relay, free of all moving mechanical parts and contacts.

70. The first of these scales of two circuits was also due to Wynn Williams(23) and utilized thyratrons, figure (39). The action of the circuit may be analysed as follows. Suppose a positive pulse is impressed on the control grids of tubes A and B, through the condensers, C_1 and C_2. Consider what happens if originally tube A is non-conducting and tube B is conducting. The positive pulse will fire tube A but does not affect tube B, whose grid has lost control. The discharge of tube A drops the voltage from grid to plate to about 17 volts, the ionization potential of argon. The drop in potential of the plate of tube A is transmitted to the plate of tube B by the condenser C_3. But since tube B is conducting its plate is at low potential to start with, and the additional negative pulse from the plate of A throws the plate of tube B negative with respect to its cathode. This extinguishes the discharge in tube B and allows its grid to regain control. As a result of the arrival of the original positive pulse the discharge has been switched from tube B to tube A. Since the circuit is symmetrical, the next positive pulse applied to C_1 and C_2 again switches the discharges. The condenser C_4 can receive a positive pulse only when tube B becomes non-conducting, which means that C_4 transmits a positive pulse to the vacuum tube triode C only once for every two input positive pulses. The triode C is biased so that it is unaffected by negative pulses, but passes a positive pulse on to the next scale of two every time a positive pulse is impressed on its grid.

71. The thyratron de-ionization time limits its speed to 10,000 per second of regular pulses. The main disadvantages of thyratron scaling circuits are (1) a tendency to block at high speeds (both thyratrons of a scale of two go into the conducting state), and (2) the relative instability and variability of thyratron tubes compared to hard vacuum tubes.

72. In the last few years, a few successful hard vacuum tube scaling circuits have been published(26, 27, 29). The simplest of these uses triodes (figure 35). The circuit is a regenerative two stage amplifier with the distinguishing feature that the output of tube A is directly coupled to tube B by a resistor from plate of A to grid of B, and similarly tube B is resistance coupled to tube A. Pulses are applied to the grids in parallel through RC coupling. Suppose a small pulse is applied to the grid of either tube. It is amplified by that tube and then by the second tube due to the coupling of plate to grid. The regenerative process begins, with the amplified pulse in the second tube further exciting the first tube, and continues until one of the tubes is driven to plate current cut-off, due to negative potential on its grid. The process then stops, leaving the

circuit in a stable state, with one tube fully conducting and the other completely cut off. The grid potentials are given by the plate potential of the opposite tube minus the IR drop in the coupling resistor. The circuit remains in an equilibrium state only because of the direct coupling.

73. Assume that the circuit is originally in a state with tube A conducting and the B non-conducting. If a negative pulse is fed to the circuit it will be amplified by A. (A positive pulse would be amplified by B). The regenerative cycle is initiated and continues until A is cut off, with B conducting. The direct coupling causes an extremely rapid phase reversal of the tubes. The next pulse will trip the circuit back to its original equilibrium state. An increase and decrease of the plate potential of tube B will occur on alternate input pulses and by transmitting these pulses to the rectifier stage C, only one output negative pulse will result for each two input pulses.

74. Any tendency of the circuit to remain in one equilibrium state due to assymmetry is overcome by the use of condensers in parallel with the coupling resistors.

75. The coupling resistors are chosen large enough to drop the voltage from the plate supply so that high positive potential is kept off the grids and proper biasing is achieved with ordinary values of grid bias supply. If negative pulses are fed to the circuit, a larger negative bias makes the circuit trip on smaller pulses and vice versa for positive input pulses.

76. The resolving power of such vacuum tube scales of two is about 150,000 pulses per second. This would permit counting 5,000 random pulses per second with about 3% loss. Methods are available for increasing the resolution of these scale circuits to almost 300,000 pulses per second. (Communications Security Section, Radio Division of Naval Research Laboratory)

D. Frequency Meter Circuits

77. The second method of indicating counting rates is by the use of frequency meter circuits. The simplest of these and probably the simplest of all methods of indicating counting rates is the circuit shown in figure 40, for use with vapor counters. The discharges in the counter produce a fluctuating current flow through the resistor R. If a condenser C is placed in parallel with R, the fluctuations are greatly reduced and a fairly steady IR drop results when the G. M. counter receives a constant intensity of radiation. The plate current in the triode is controlled by the voltage on the grid and is proportional to the number of pulses per unit time. A milliameter M in the plate supply serves to indicate intensity. The reading of the meter is adjusted to zero for zero pulses per second with the aid of a bucking circuit.

78. By selecting different values of R and C the circuit may be adjusted to cover a range of about 10^7 in intensity. This circuit is ideal for work requiring simple detection of peak intensity. It has been used with counters for locating crystallographic planes in quartz by x-ray reflection at the piezoelectric crystal-cutting laboratory of the Washington Navy Yard.

79. The main disadvantages of the above circuit are (1) its sensitivity to the high voltage applied to the counter, and (2) deviation from proportionality at higher counting rates. The pulse size in a vapor counter is dependent on the over-voltage and at high counting rates the pulse size falls off because the counter does not fully recover to the original over-voltage between pulses. The first difficulties may be overcome by use of a circuit such as shown in figure 41. The 6SQ7 tube has the characteristic that a negative pulse of about two volts on the grid completely cuts off the plate current. So long as the pulses from the counter are greater than two volts, the output pulse at the plate of the 6SQ7 tube will be constant. The diode unit serves to rectify the plate pulses that are fed to the 6C5 stage. The output of this circuit is therefore directly proportional to the number of input pulses per second irrespective of their size so long as the counting rate is not so high that pulses overlap.

80. The most popular device for producing counter pulses of uniform height and shape in the multivibrator. The Getting (11) circuit shown in figure 42 also aids the quenching action of the G. M. counter. The multivibrator circuit is very similar to the vacuum tube scale of two circuit discussed above, except that the direct coupling from plates to grids is removed leaving the two triodes with only condenser back coupling. Tube B is biased to cut-off (figure 39) and tube A is normally conducting. In this condition, a momentary surge of voltage on the grid of either pentode produces a rectangular voltage pulse at the plate of tube B. The circuit responds to positive pulses if applied to tube B and to negative pulses if applied to tube A.

81. Suppose a short negative pulse from the counter is applied to the grid of tube A, at a time t_1. As the grid goes negative plate current decreases, passing a positive pulse to the grid of tube B. The process is regenerative and continues until the plate current of tube B reaches a maximum limited by its plate resistor, with its plate potential at a low value. Simultaneously, the grid of tube A has been forced to an extremely negative value, slightly less than the plate supply voltage, which it maintains until the negative charge leaks from the grid to ground through the one megohm resistor. As the charge leaks of C_2, the grid of tube A goes less negative exponentially until it passes the critical cut-off value at a time t_2. Tube A then becomes conducting again and the grid of tube B goes very negative, cutting off the plate current. The grid of B now recovers exponentially but because of the negative bias, it does not reach the critical cut-off voltage. If the grid bias is reduced so that cut-off voltage is reached, the circuit becomes self-oscillatory. The minimum input pulse size to which the multivibrator will respond is determined by the size of the grid bias. The circuit may be adjusted to respond to a pulse size of the order of 0.01 volt and amplify it a few thousand times.

82. The make and break of plate current in each tube is extremely fast, which gives the straight sides to the output pulse. The length of the pulse from tube B is determined by the time required for charge to leak off C_1 and is given approximately by $R_2\ C_1(\log\mu)$ where μ is the amplification factor of the tube. The resolving time of the circuit is approximately given by $R_2\ C_1 \log\mu + R_1\ C_2$.

83. While the initial lowering of the grid potential due to flow of current from the counter wire through R would not extinguish the discharge in the counter, the regenerative effect of the coupling, throws the entire available voltage drop of the plate of tube B back onto the counter wire, quickly quenching the discharge. It is therefore possible to dispense with the 10^9 ohm resistance generally in series with the counter and use only one megohm. The recovery time is then given by the circuit constants. With the constants indicated in Figure 42, 2000 random pulses per second can be counted. The maximum rate is the oscillation frequency of the circuit when self-excited.

84. A disadvantage of the circuit when high counting rates are to be measured is that the voltage range of the counter becomes limited. To obtain high speed in the multivibrator, it is necessary to reduce the coupling capacitors and grid resistors, but then the increased speed is gained at the expense of signal amplitude fed back to the counter wire. Since it is this output signal of the multivibrator that quenches the counter, the counter cannot be operated at an over-voltage greater than this pulse. For relatively slow counting, the Getting multivibrator easily allows for plateaus over one hundred volts long, but at high speeds this range is greatly cut down. A multivibrator circuit that was designed to overcome this disadvantage is shown in Figure 43. Here the high voltage is applied directly to the plate resistor of the second tube and the wire of the counter. The action is exactly the same as in the circuit previously described, but now the entire H.V. is available for the quenching pulse returned to the counter wire. The action of this circuit has been found much more positive than that of the Getting circuit. It is being used in the exposure meter circuits (Report M-1799) and wherever good stability is desired.

85. At very high counting rates, the multivibrators are not fast enough and the scale of two unit (Figure 38) has been utilized as a uniform pulse generator. This type of frequency meter has a resolving power of between 150,000 and 200,000 pulses per second, almost 100 times greater than the multivibrators that have been described. The circuit does not respond to input pulses under a given size, and high amplification of the counter pulses is desirable to assure tripping of the circuit on even the weakest pulses. This is clearly demonstrated by Figure 52 where the 7 tube counter of Plate (26) was used in conjunction with the above frequency meter circuit. The difference in the two cases was simply one of amplification of the counter pulses before feeding the scale of two type of uniform pulse generator. Curve A is the characteristic curve obtained with a high gain two stage amplifier. The plateau length is about 140 volts. In Case B, only a Harper-Neher stage was used between the counter and uniform pulse generator. The effective plateau length was reduced to less than ten volts. (Both curves were taken at high counting speeds.) The circuit of Figure 35 is recommended for very high speed counting with fast vapor counters and in conjunction with the Harper-Neher circuit for rapid counting with non-vapor counters.

E. Stabilizers

86. No counters have perfectly flat plateaus. In ordinary tube counters, the slopes of the plateaus may be anywhere from 0.1% per volt to 2.0% per volt, and for complicated parallel combinations, these slopes

may be even higher. The importance of stabilizing the high voltage applied to the counter is obvious, if constancy of counter response is desired.

87. One of the simplest methods of control employs neon glow lamps as stabilizers (Figure 44). These lamps have the characteristic property of glow tubes, that the resistance decreases with increasing current. If the voltage across the electrodes tends to rise during discharge the resistance drops and the current drain on the supply increases, holding the voltage down. The reverse happens when the voltage tends to drop. Each neon lamp of the 1/25 watt size stabilises at about 60 volts. By arranging a series of such lamps in the manner shown in Figure 41, any stabilized voltage may be picked off for the counter. If the current drain consists only of that drawn by the counter, good stabilization is achieved as shown in Figure 45. At larger current drains the stabilisation becomes rapidly poorer. The main objection to this method of obtaining stable high voltage for the counter is a tendency of the glow lamps to leak slowly and change their characteristics.

88. A method which has been found much more satisfactory for obtaining fixed stabilized high voltages at low current drain is the use of another G. M. tube counter as a glow tube. The action is fundamentally the same as that in the neon tube method. As the voltage tends to rise the current density remains constant, but the total current increases by a spreading of the discharge over the surface of the electrode. The voltage across the tube remains practically constant until the glow covers the entire electrode.

89. To obtain good regulation for all possible current drains during operation of the counter, large electrode area is necessary and a tube length of over 4 feet was required to give desired stability. Rather than use a long tube, seven tubes, each 20 cms. long were connected in parallel (Plate 41). The discharge voltage of the tube depends on the nature of the gas and electrode geometry. The stabilised voltages obtained with air at various pressures are shown in Figure 46. The curve of input voltage against output voltage with a current drain of 25 microamperes (Figure 47) shows less than 0.1% change in output voltage for 100% change in input voltage.

90. One of the best vacuum tube stabiliser circuits is shown in Figure 48 and its stabilisation characteristics in Figure 49. The stabilization is excellent even at high current drains, due to the tube T_2, which acts as a constant current device. It is relatively insensitive to fluctuations in heater power input and shows almost negligible drift with time. It is particularly recommended for use with counters operated in the proportional counting range, where extreme constancy of high voltage is necessary.

91. For most counter work, the stabiliser shown in Figure 50 is satisfactory. The circuit of Figure 45 requires insulated screen voltage and grid bias supplies which must be obtained from batteries. In Figure 50, the grid bias is controlled by a small 2 watt neon bulb and the entire circuit may be built compactly. The stabilization characteristics at 200 microampere current drain are shown in Figure 51. There is very little drift in operation.

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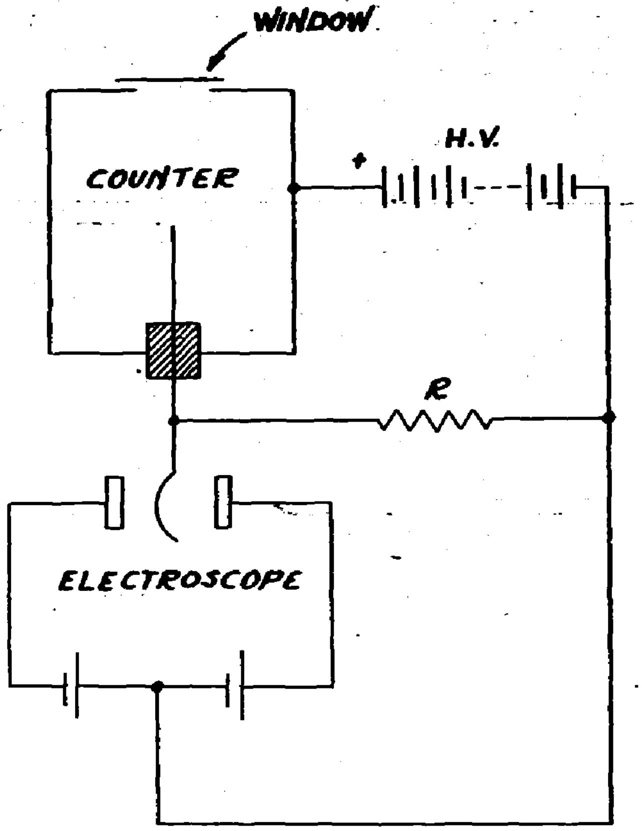
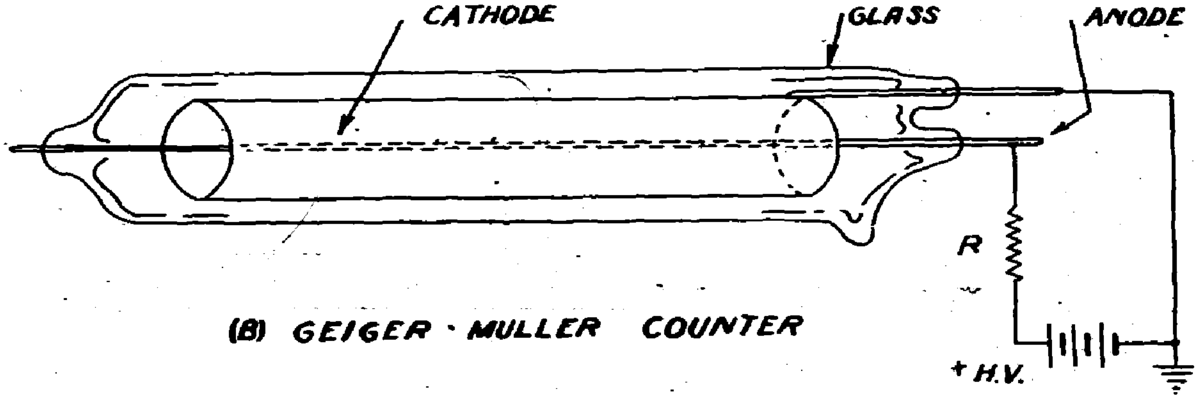
(33) D. W. Kerst, R.S.I. 9, 131 (1938) "A High Resolving Power Tenfold Thyratron Counter"
(34) R. D. Evans and R. D. Alder, R.S.I. 10, 332 (1939) "Improved Counting Rate Meter"
(35) R. D. Evans and R. E. Meagher, R.S.I. 10, 339 (1939) "A Direct Reading Counting Rate Ratio Meter"



(A) POINT COUNTER AND ELECTROSCOPE RECORDING CIRCUIT



(B) GEIGER · MULLER COUNTER

FIG. 1

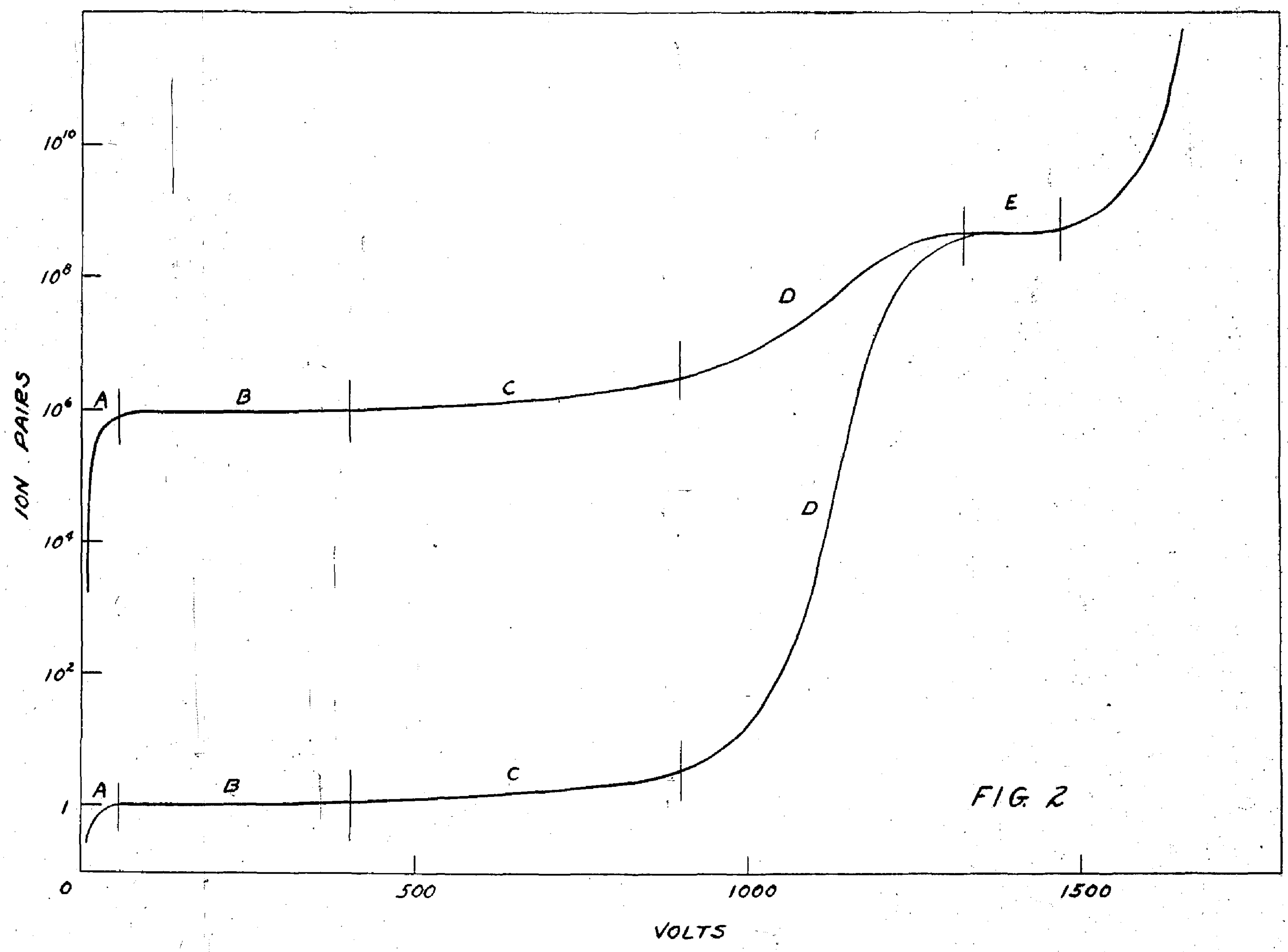


FIG. 2

PLATE 2

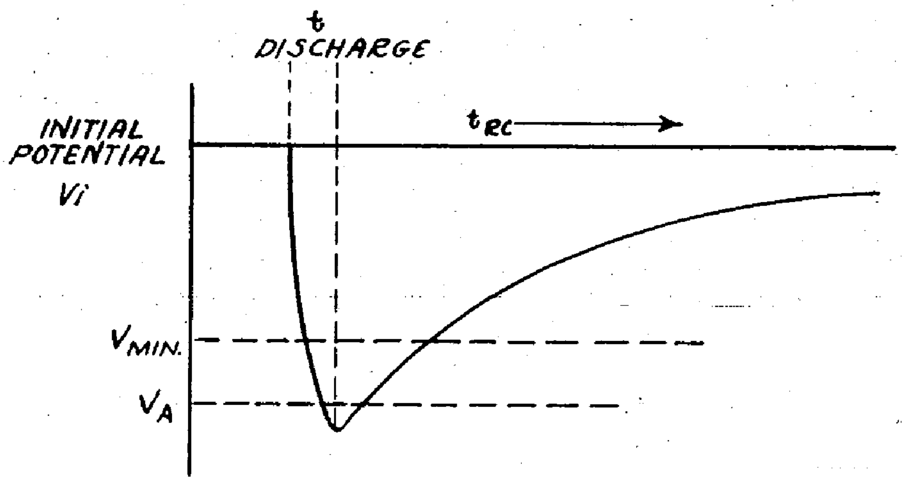

t DISCHARGE
t_{RC}
INITIAL POTENTIAL
Vi
$V_{MIN.}$
V_A

FIG. 3

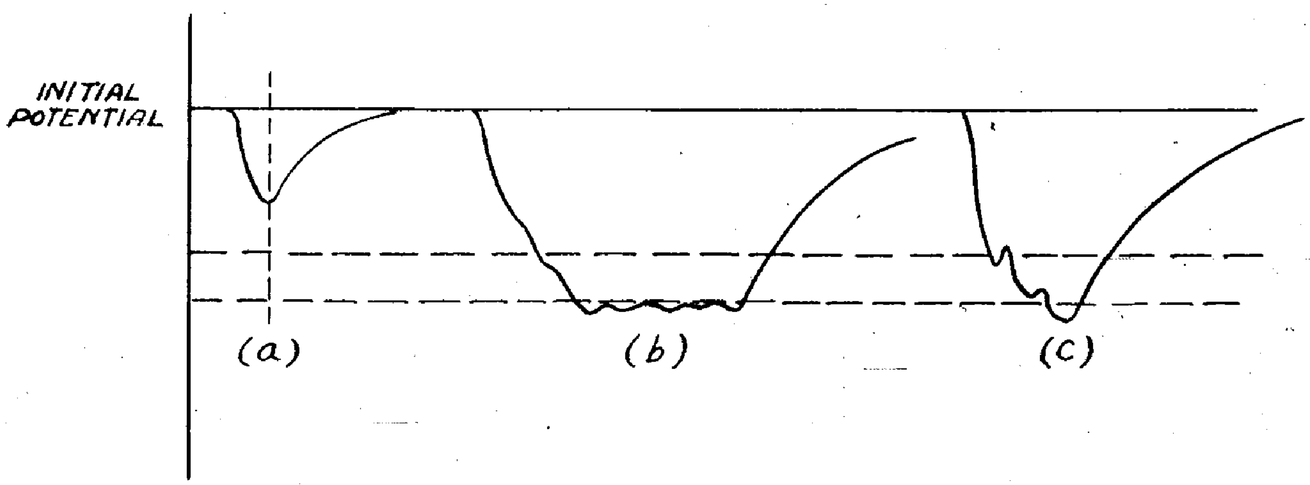

INITIAL POTENTIAL
(a)
(b)
(c)

FIG. 5

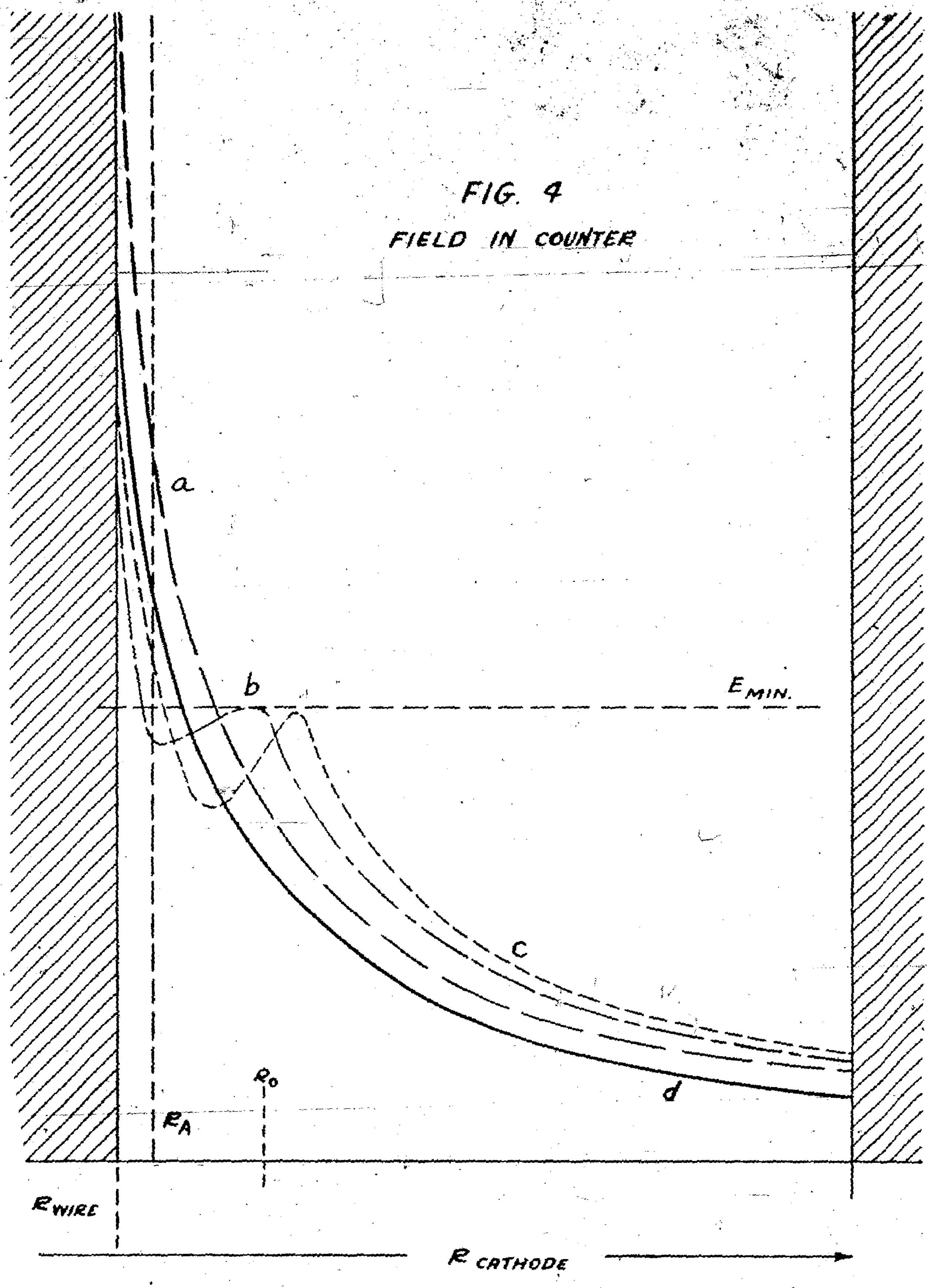


FIG. 4
FIELD IN COUNTER
a
b
E MIN.
c
d
R0
RA
R WIRE
R CATHODE

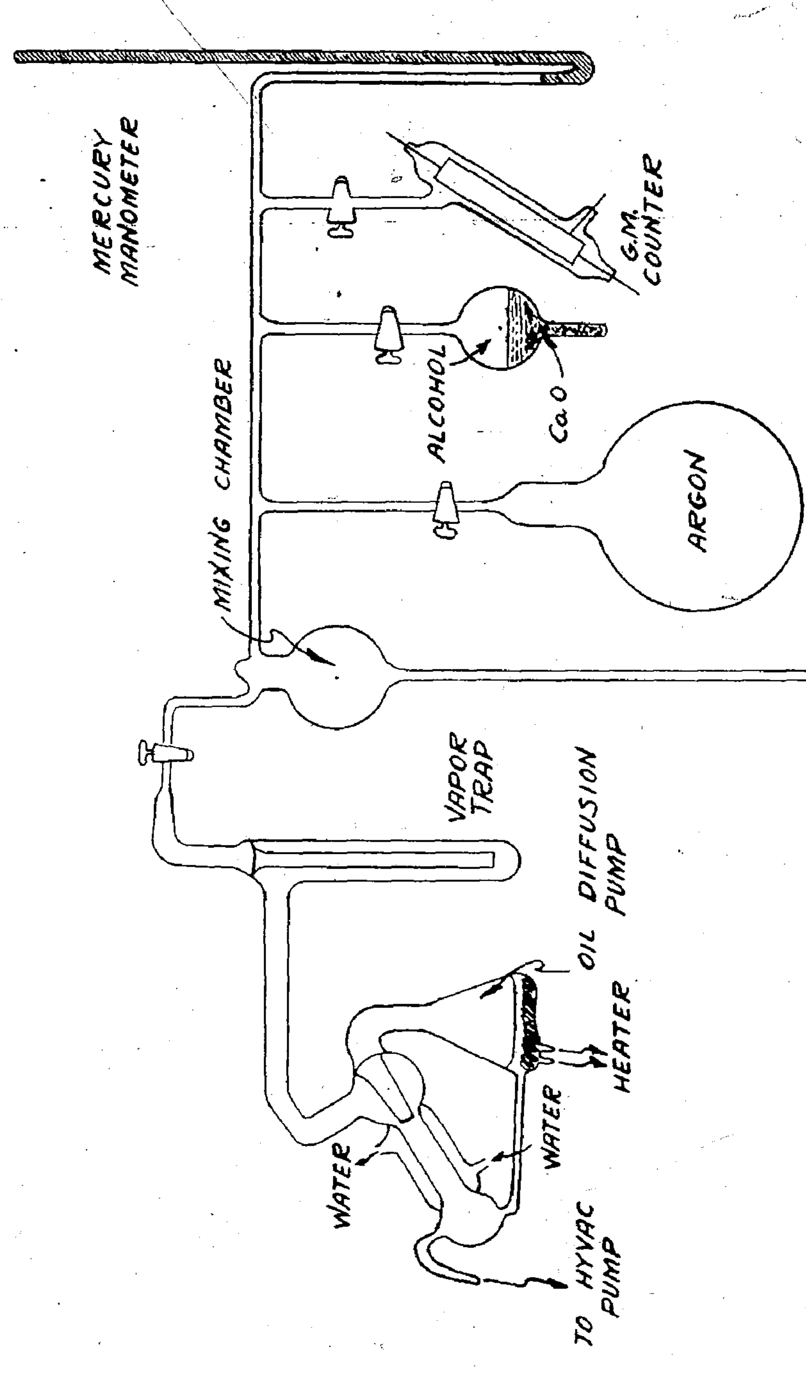
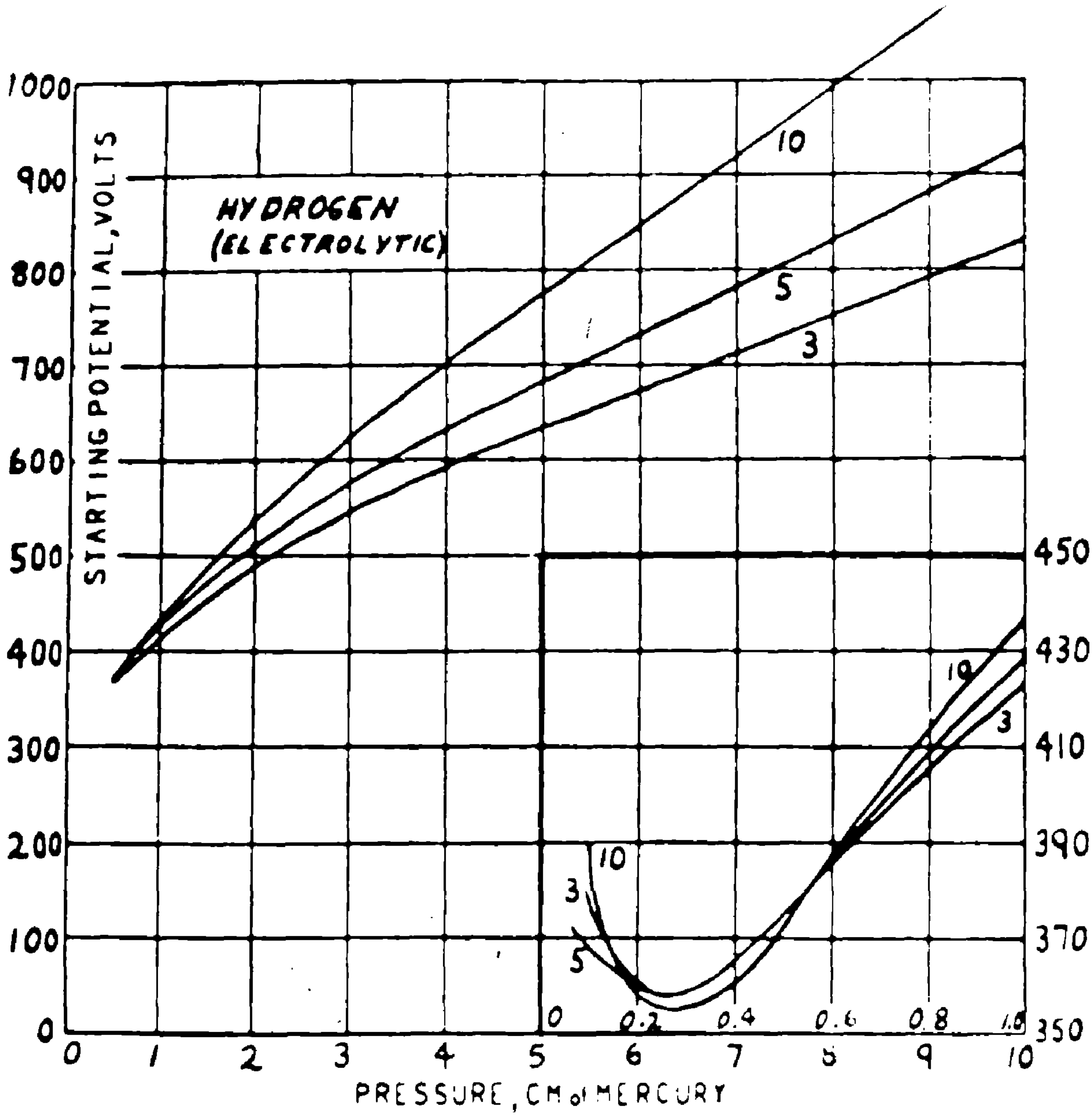

MERCURY MANOMETER
G.M. COUNTER
ALCOHOL
CaO
ARGON
MIXING CHAMBER
VAPOR TRAP
OIL DIFFUSION PUMP
HEATER
WATER
WATER
TO HYVAC PUMP
BICYCLE PUMP

FIG. 6



HYDROGEN
(ELECTROLYTIC)
STARTING POTENTIAL, VOLTS
PRESSURE, CM of MERCURY
1000
900
800
700
600
500
400
300
200
100
0
450
430
410
390
370
350
0
1
2
3
4
5
6
7
8
9
10
0.2
0.4
0.6
0.8
1.0
10
5
3

FIG. 7

PLATE 6

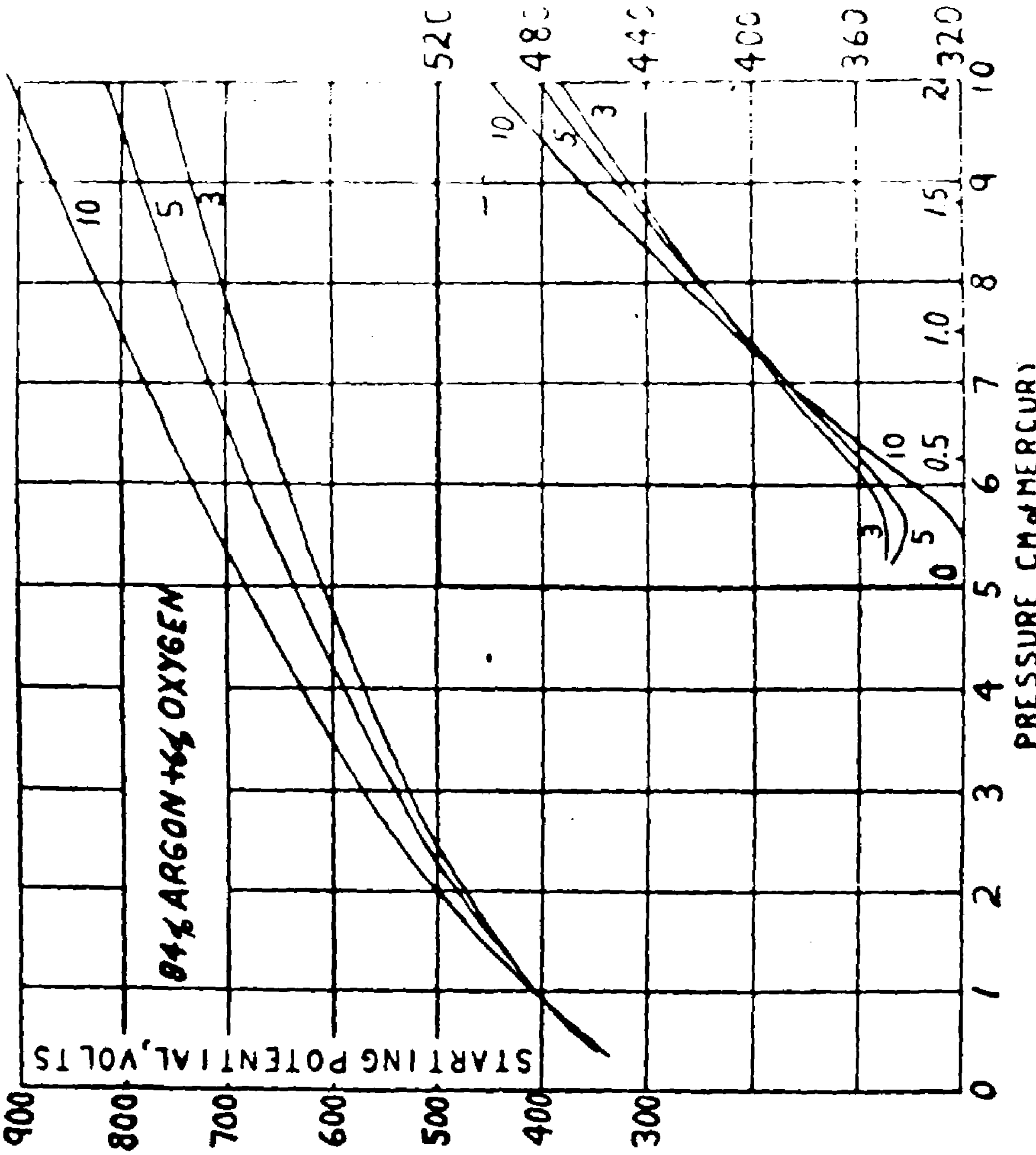

84% ARGON + 16% OXYGEN
STARTING POTENTIAL, VOLTS
PRESSURE, CM of MERCURY
900
800
700
600
500
400
300
0
1
2
3
4
5
6
7
8
9
10
520
480
440
400
360
320
0.5
1.0
1.5
2

FIG. 8

PLATE 7

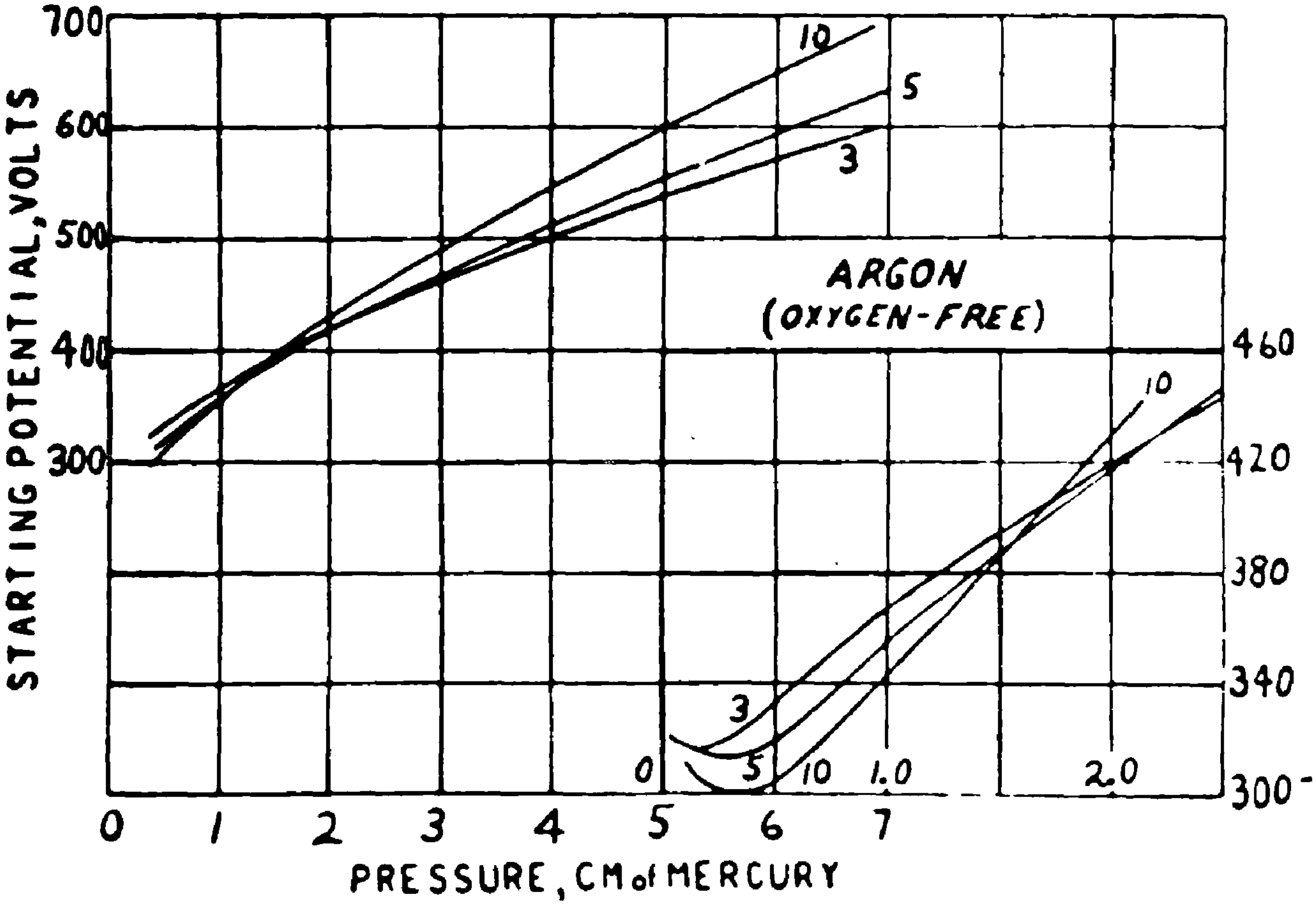

STARTING POTENTIAL, VOLTS
ARGON
(OXYGEN-FREE)
PRESSURE, CM of MERCURY
700
600
500
400
300
460
420
380
340
300
0 1 2 3 4 5 6 7
0 1.0 2.0
10
5
3

FIG. 9

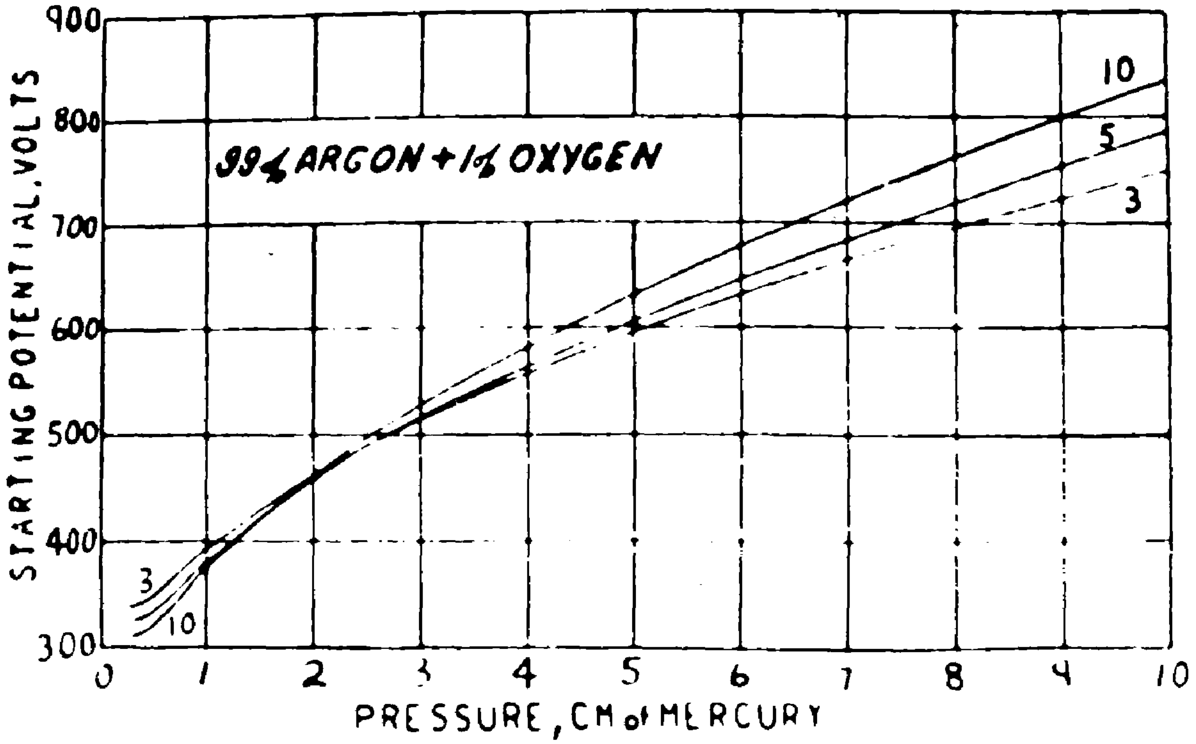

STARTING POTENTIAL, VOLTS
99% ARGON + 1% OXYGEN
PRESSURE, CM of MERCURY
900
800
700
600
500
400
300
0 1 2 3 4 5 6 7 8 9 10
10
5
3

FIG. 10

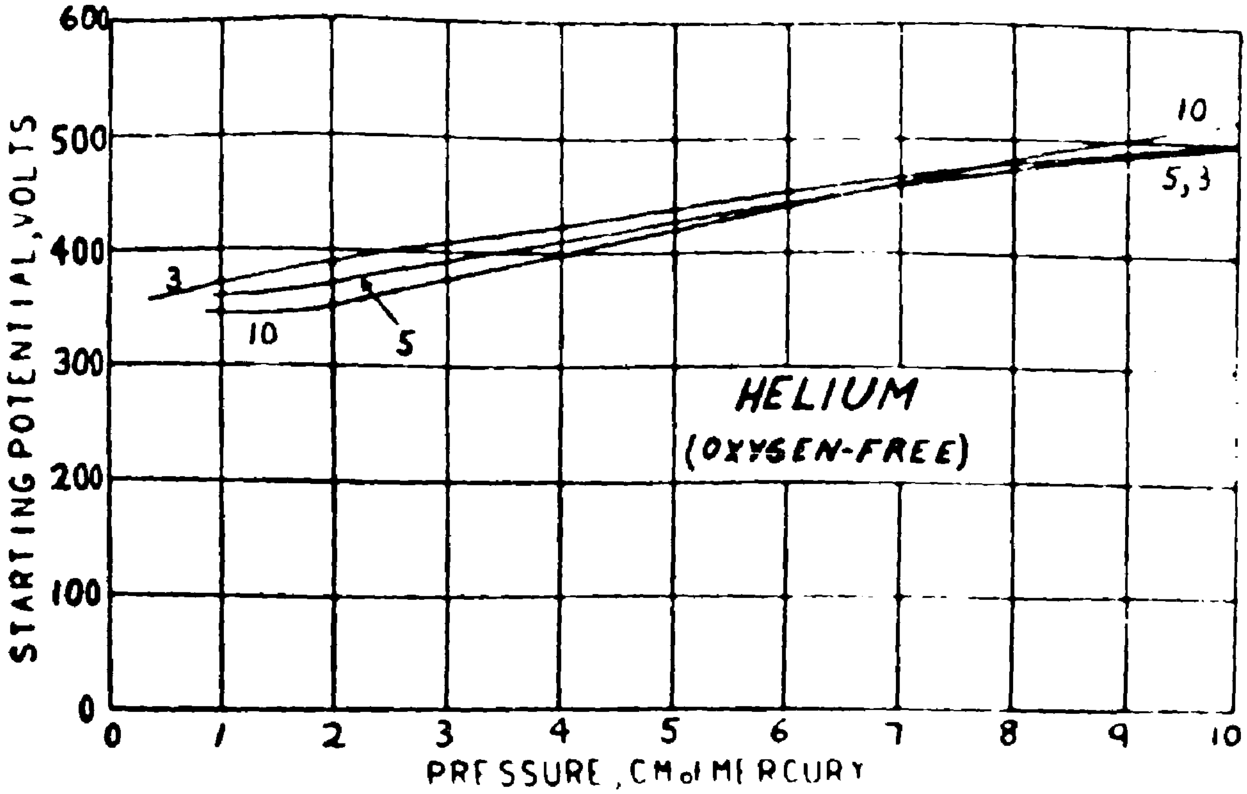

600
500
400
300
200
100
0
STARTING POTENTIAL, VOLTS
0
1
2
3
4
5
6
7
8
9
10
PRESSURE, CM of MERCURY
10
5,3
3
10
5
HELIUM
(OXYGEN-FREE)

FIG. 11

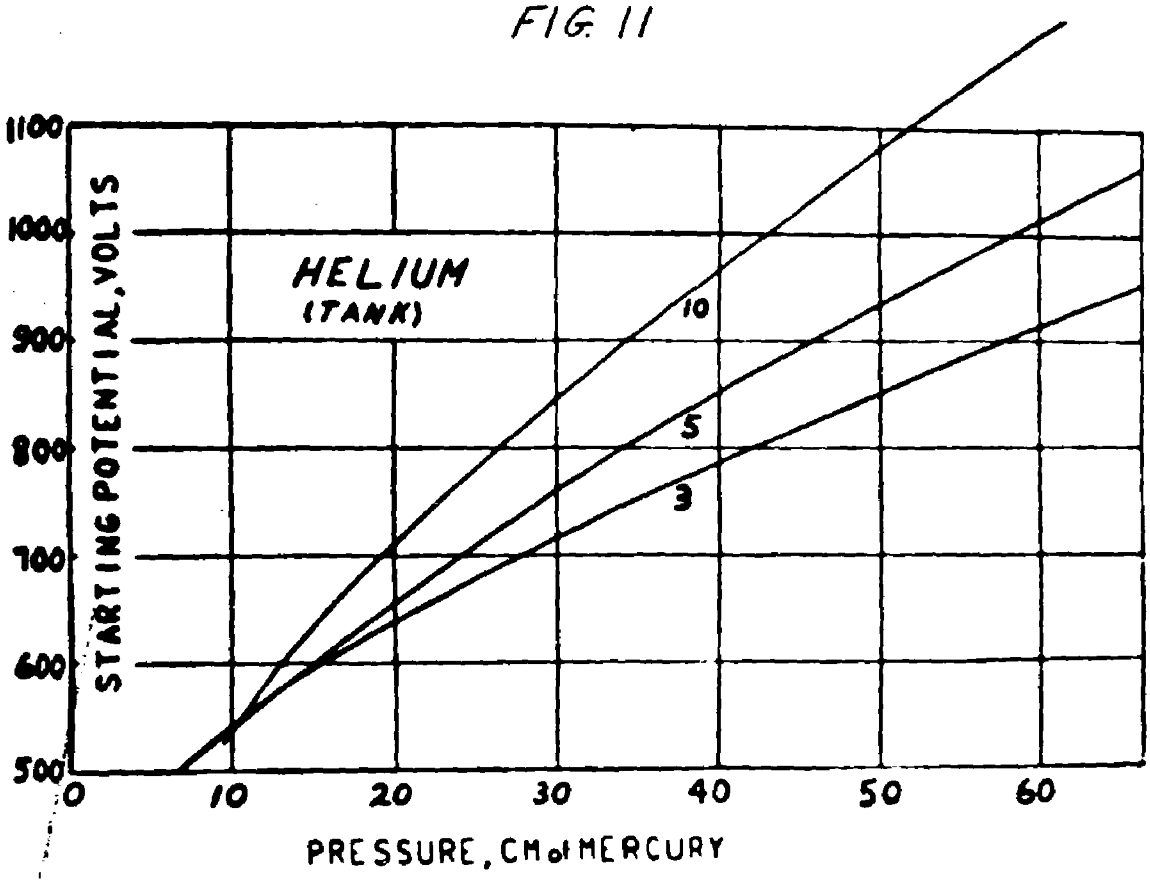
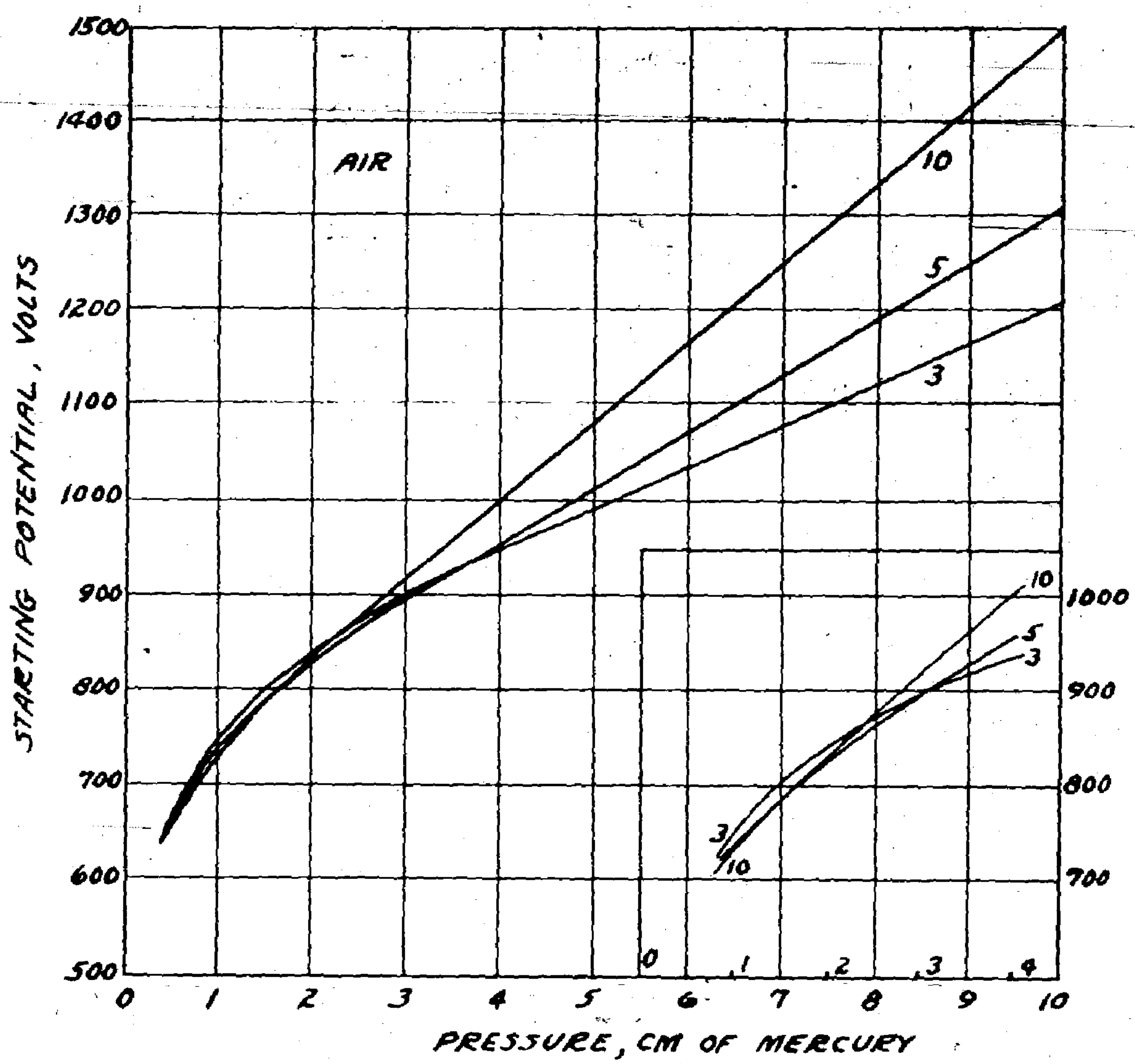

1100
1000
900
800
700
600
500
STARTING POTENTIAL, VOLTS
0
10
20
30
40
50
60
PRESSURE, CM of MERCURY
HELIUM
(TANK)
10
5
3

FIG. 12



AIR
STARTING POTENTIAL, VOLTS
PRESSURE, CM OF MERCURY
1500
1400
1300
1200
1100
1000
900
800
700
600
500
0
1
2
3
4
5
6
7
8
9
10

FIG. 13

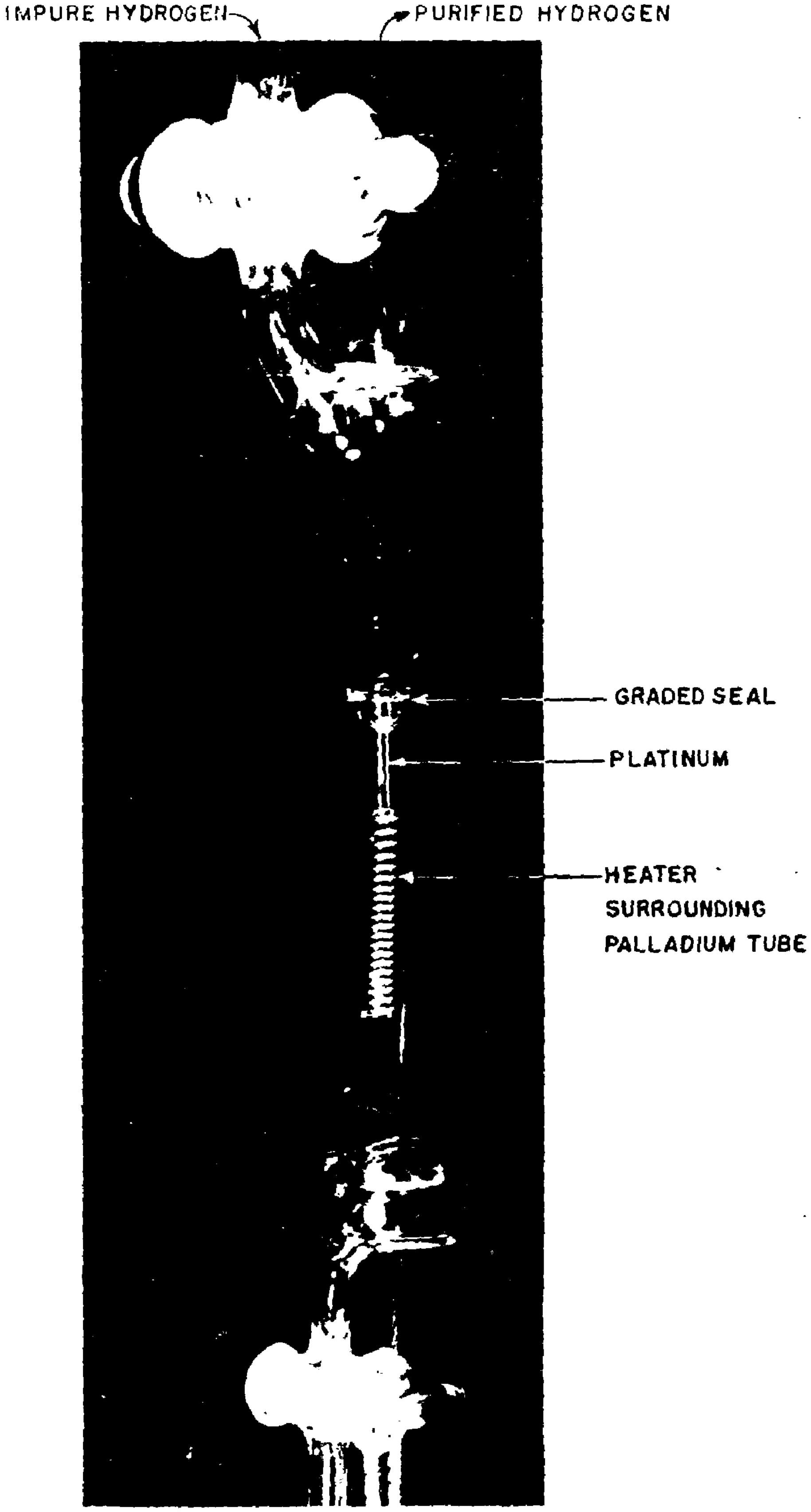


FIG. 14

PLATE II

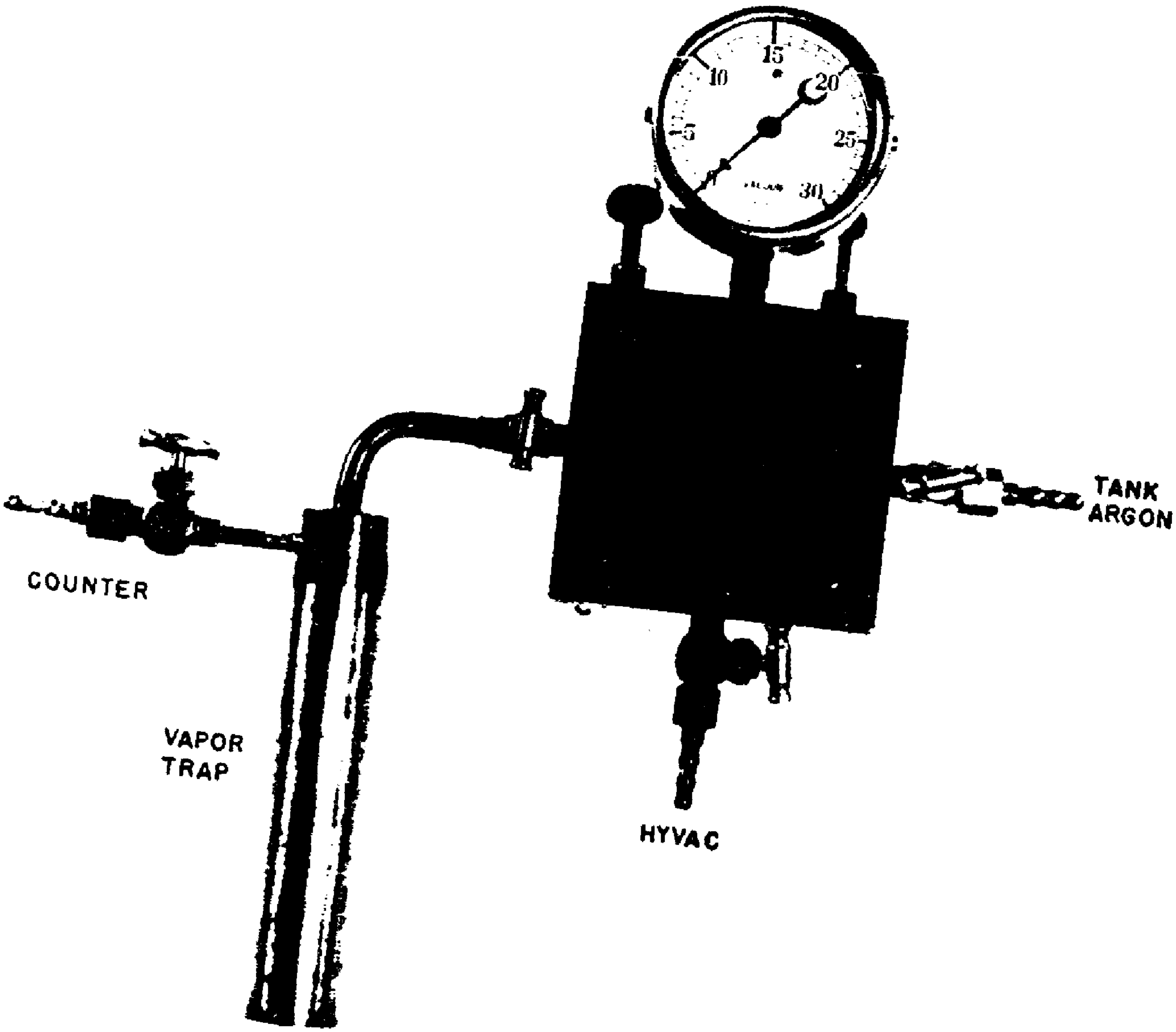
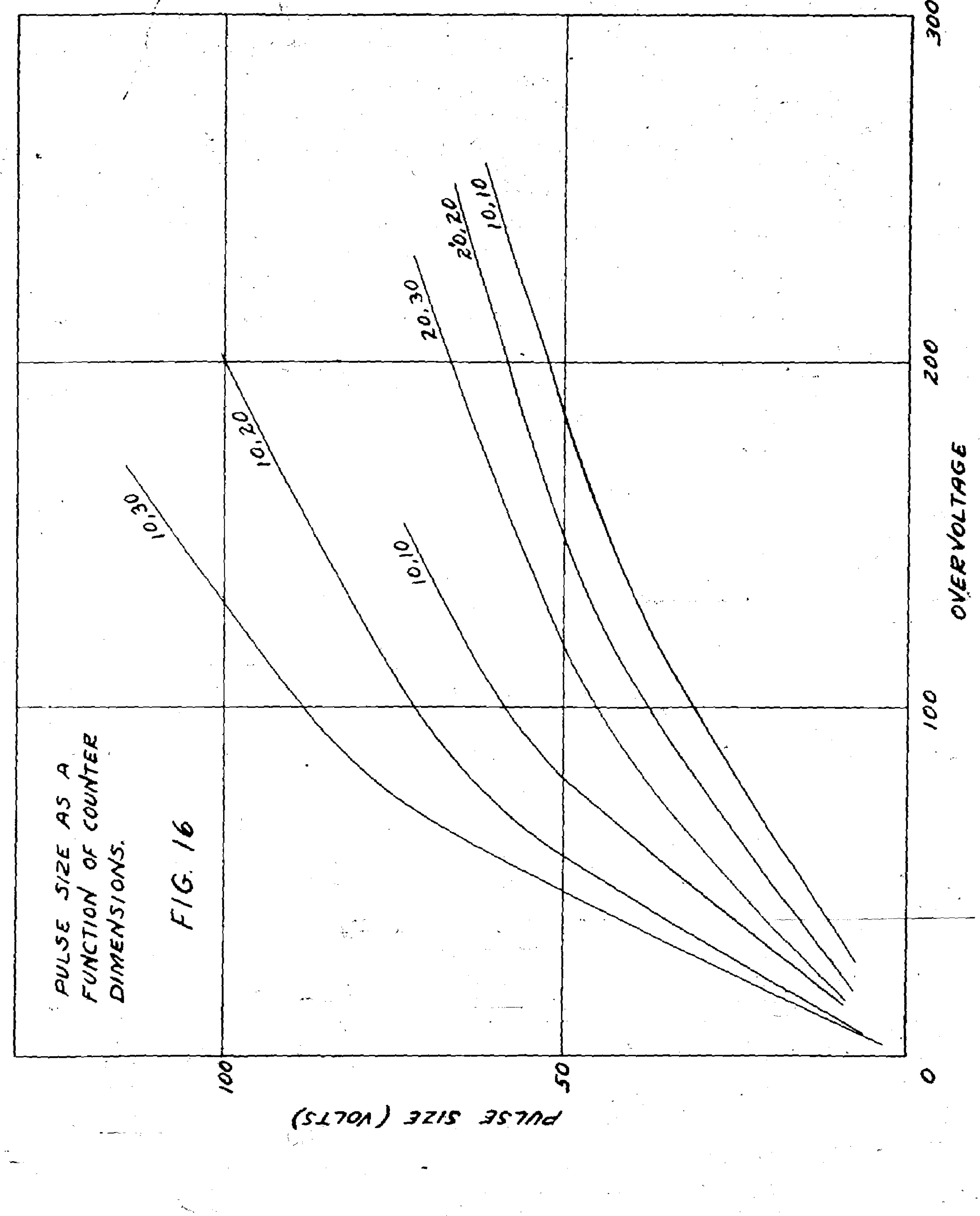


PLATE 12



PULSE SIZE AS A FUNCTION OF COUNTER DIMENSIONS.

FIG. 16

PLATE 13

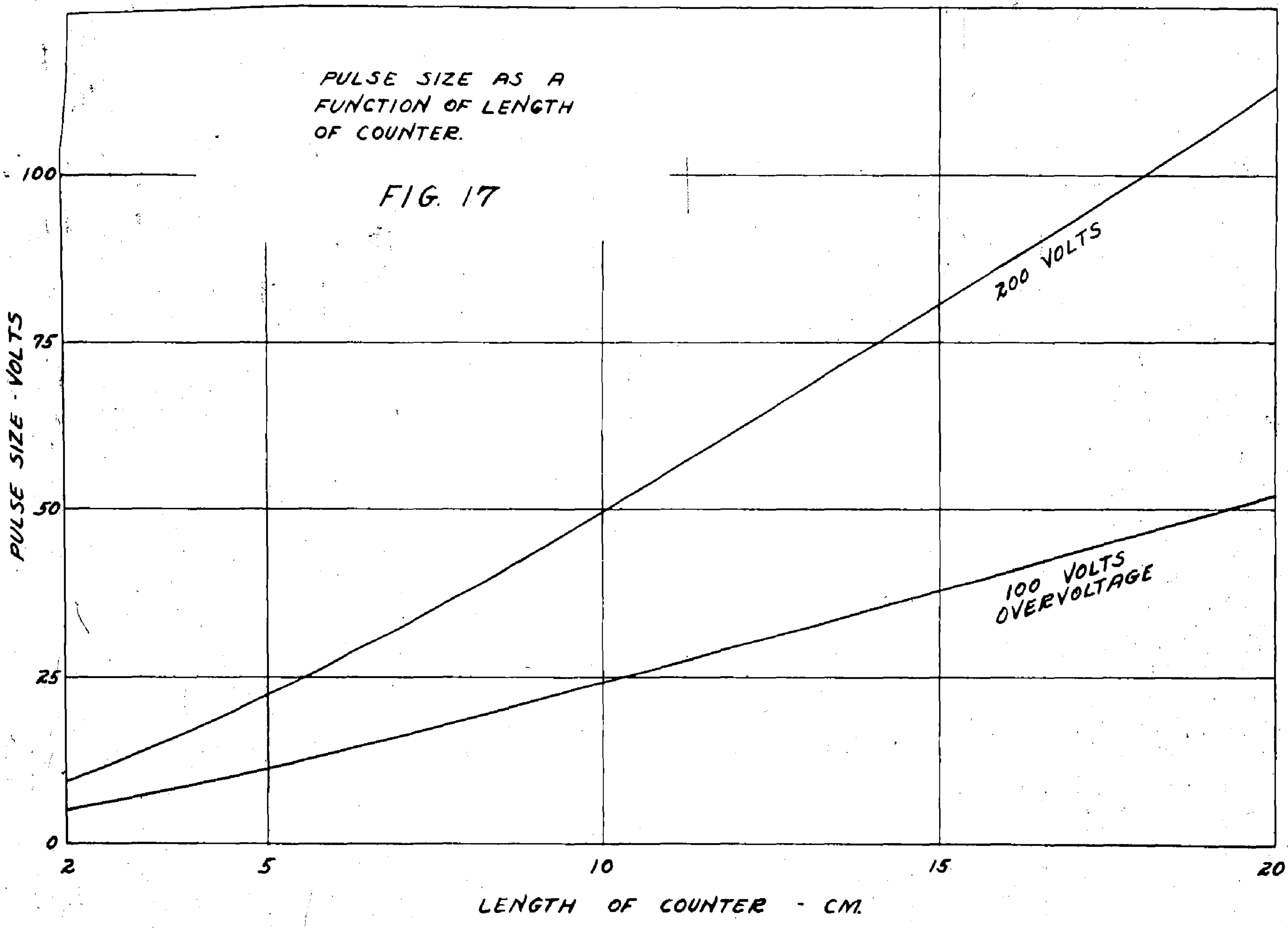
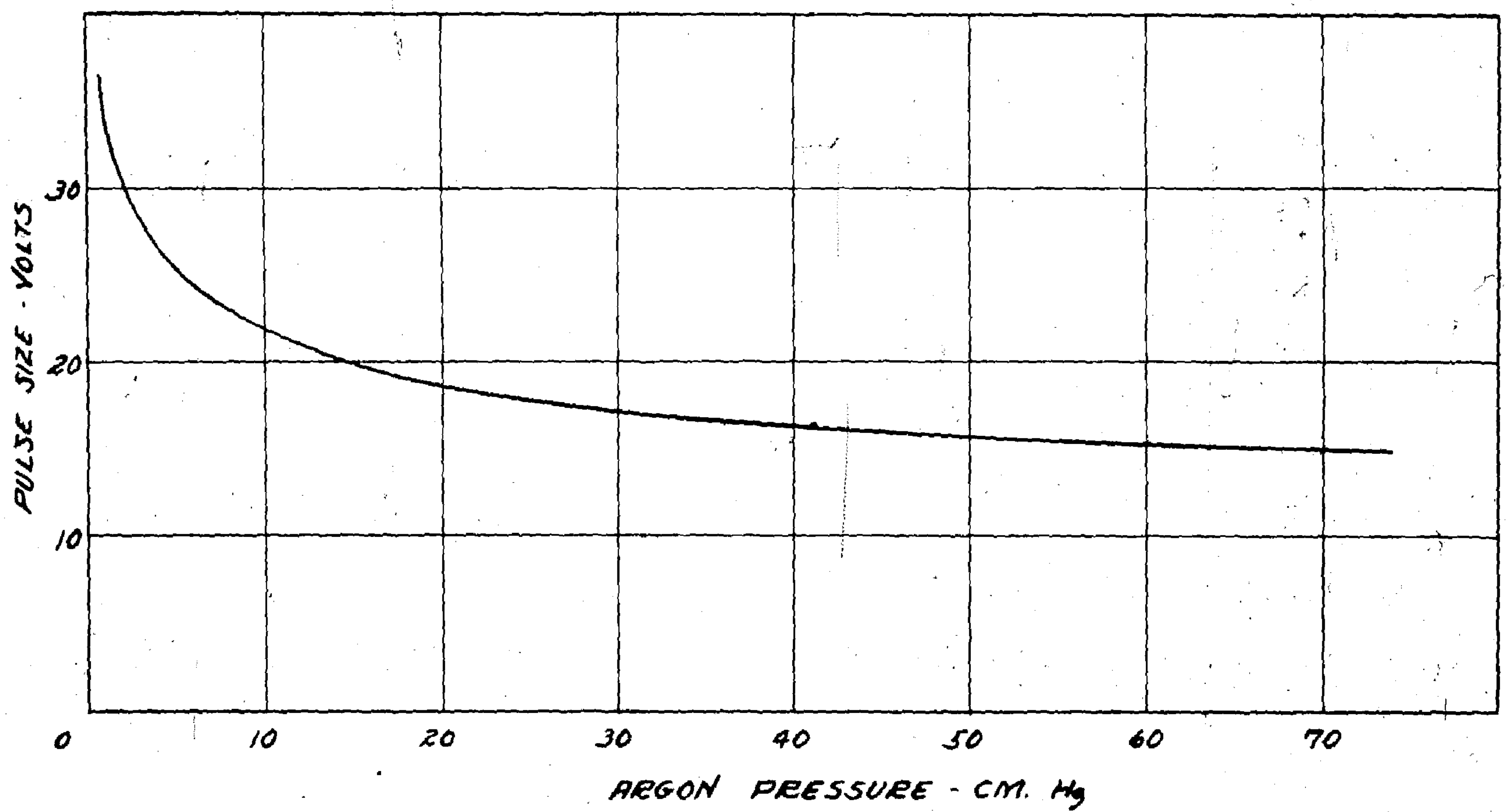

PULSE SIZE AS A FUNCTION OF LENGTH OF COUNTER.
200 VOLTS
100 VOLTS OVERVOLTAGE
PULSE SIZE - VOLTS
100
75
50
25
0
2
5
10
15
20
LENGTH OF COUNTER - CM.

FIG. 17

PULSE SIZE AS A FUNCTION OF ARGON PRESSURE FOR 6 MM. CONSTANT ALCOHOL PRESSURE.

FIG. 18



RELATIVE PULSE SIZE AS A
FUNCTION OF LEAK RESISTANCE
IN SERIES WITH COUNTER

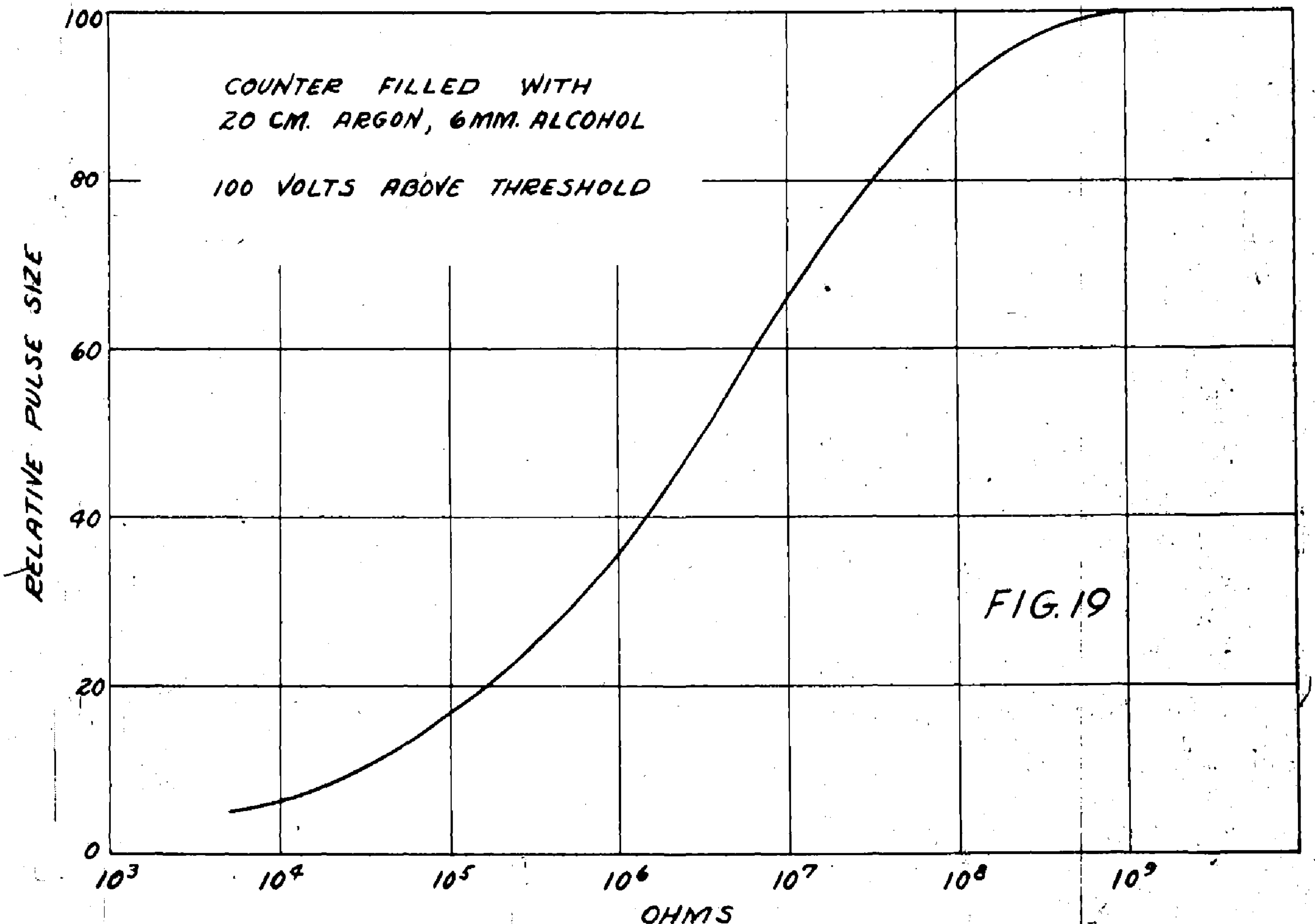


FIG. 19

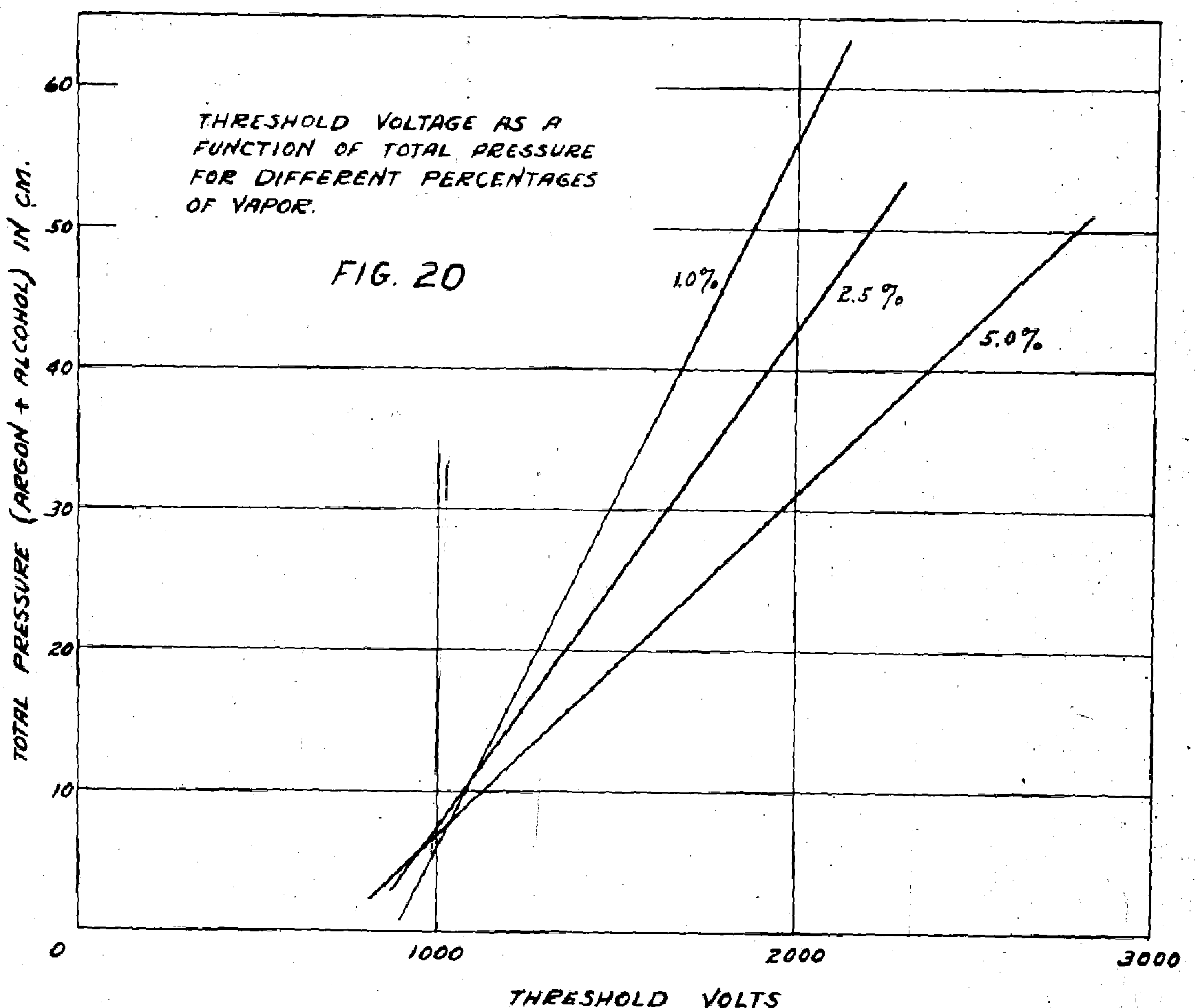

THRESHOLD VOLTAGE AS A FUNCTION OF TOTAL PRESSURE FOR DIFFERENT PERCENTAGES OF VAPOR.
FIG. 20
1.0%
2.5%
5.0%
TOTAL PRESSURE (ARGON + ALCOHOL) IN CM.
0
10
20
30
40
50
60
1000
2000
3000
THRESHOLD VOLTS

PLATE 18

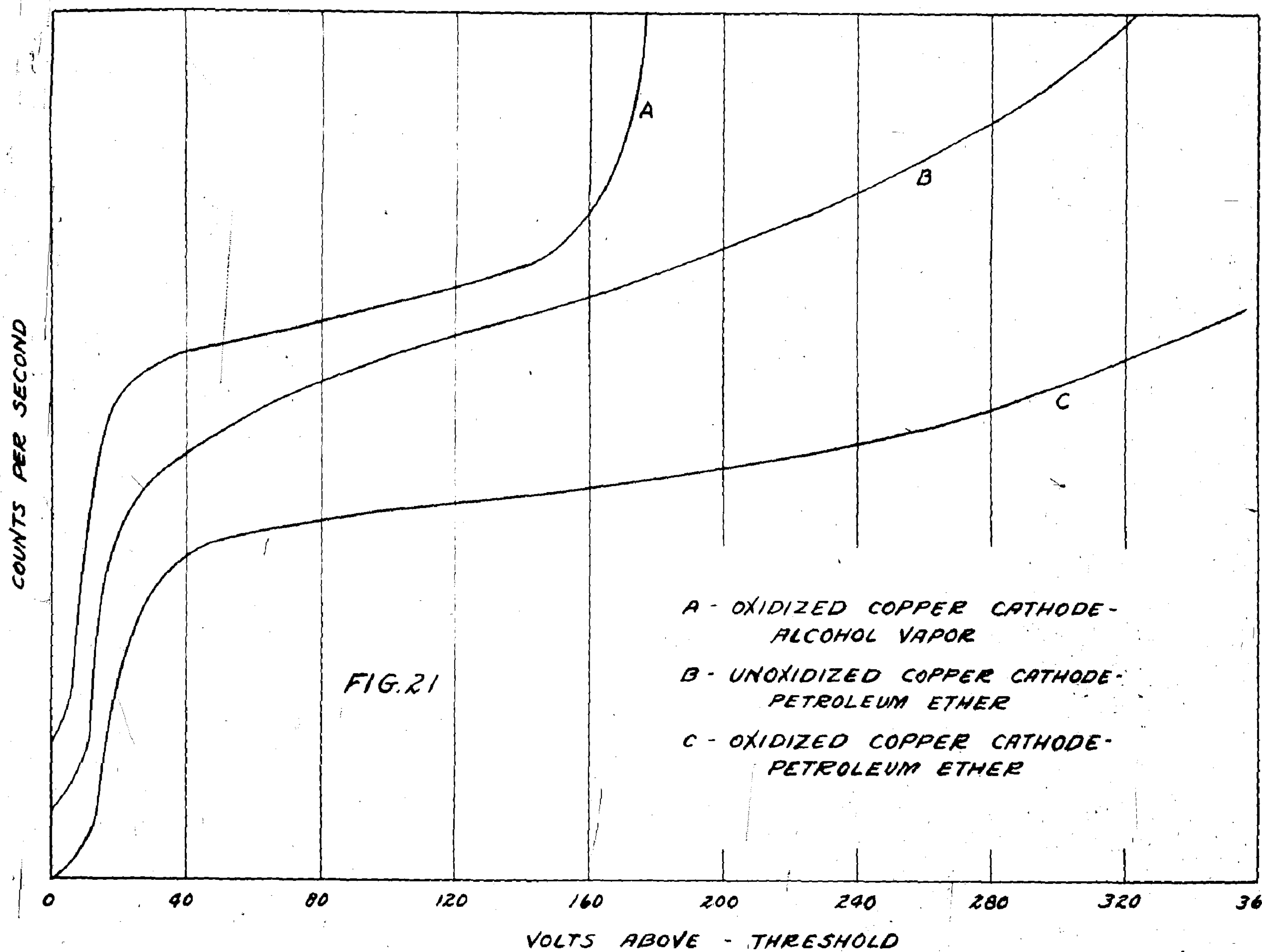
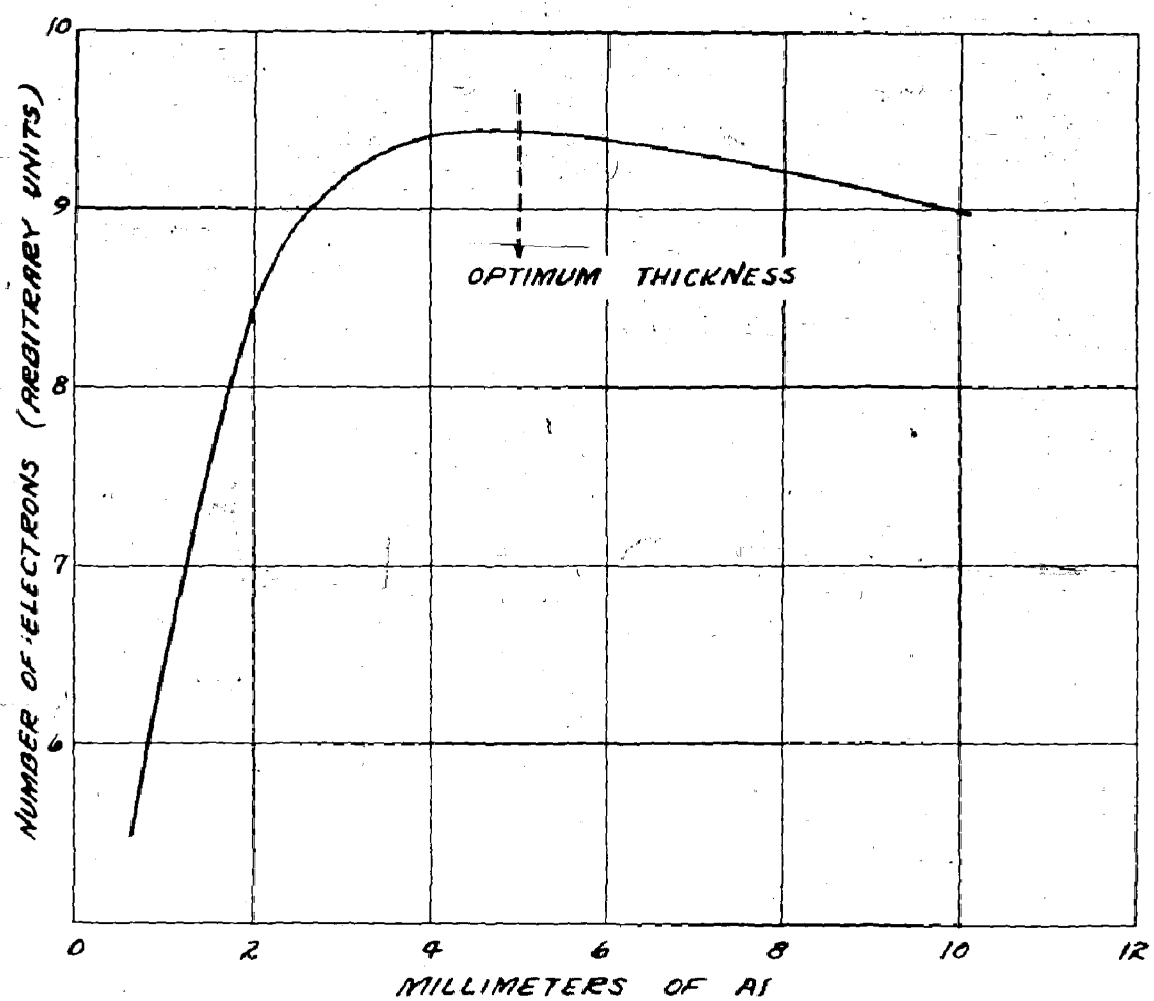


FIG. 21



INTENSITY OF ELECTRONS EMERGING FROM ALUMINUM SURFACE AS A FUNCTION OF ALUMINUM THICKNESS FOR CONSTANT GAMMA RAY INTENSITY.

FIG. 22

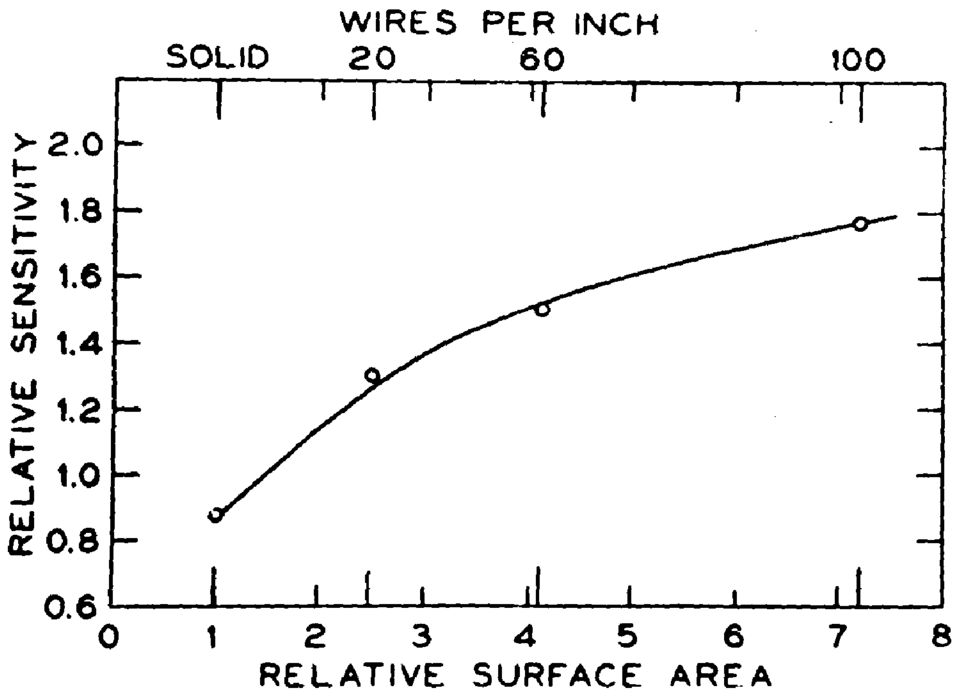

WIRES PER INCH
SOLID
20
60
100
RELATIVE SENSITIVITY
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0
1
2
3
4
5
6
7
8
RELATIVE SURFACE AREA

FIG. 23

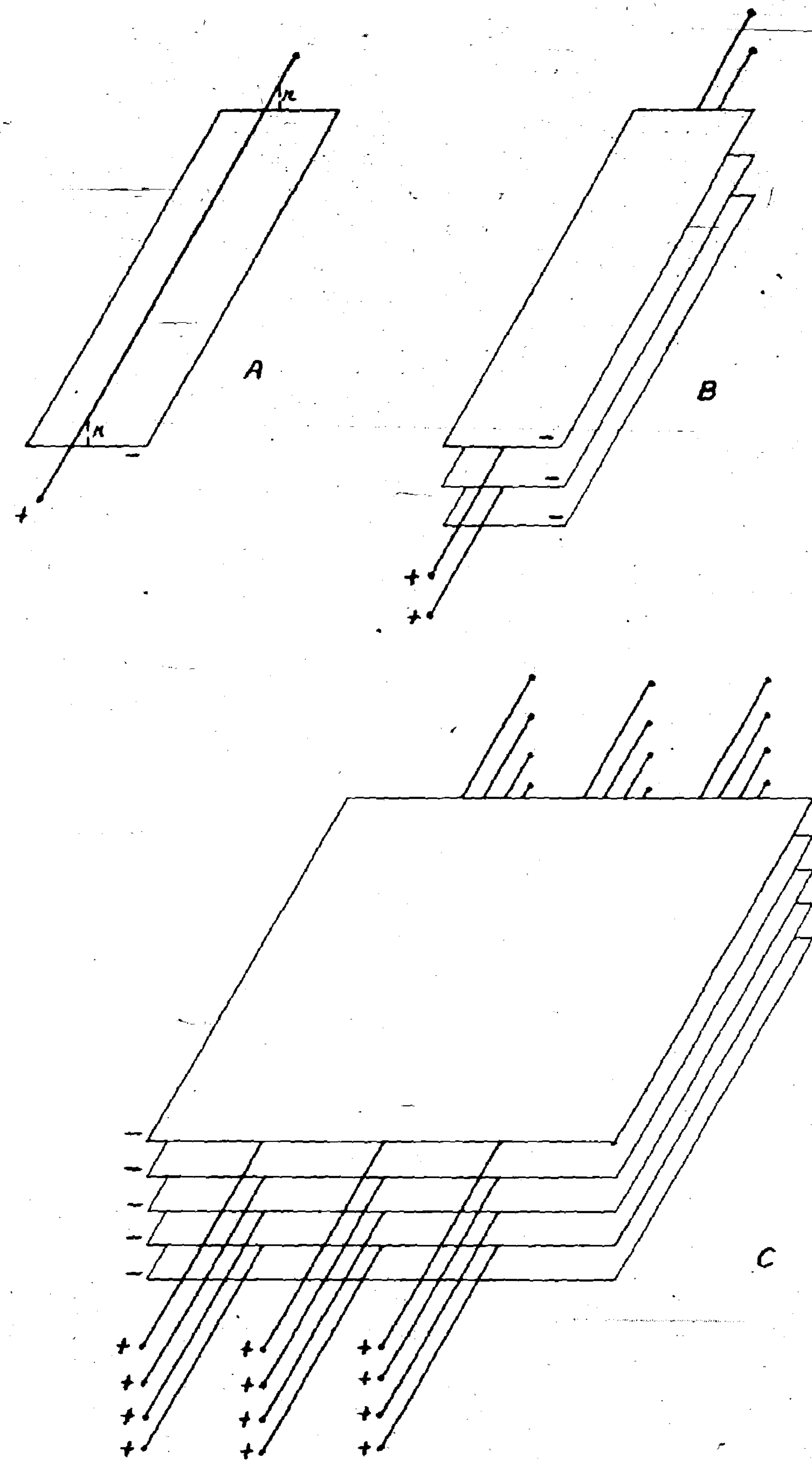


FIG. 24

FIG. 25

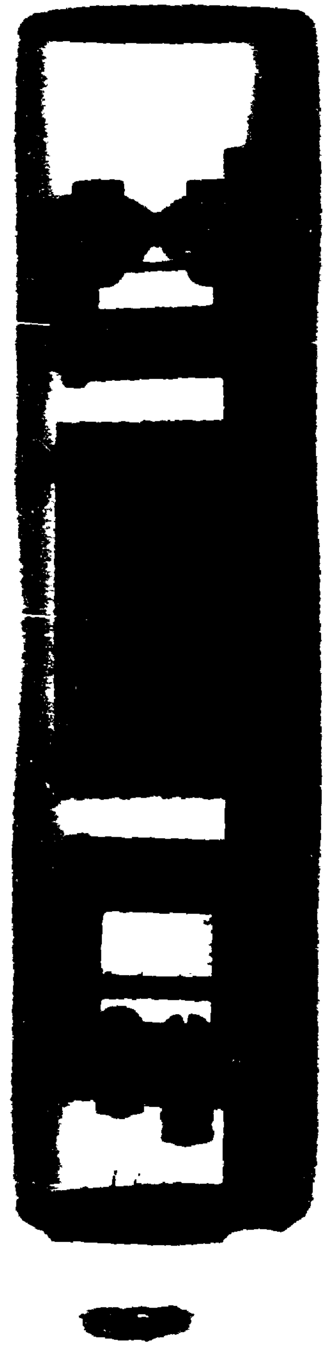


FIG. 26

PLATE 22

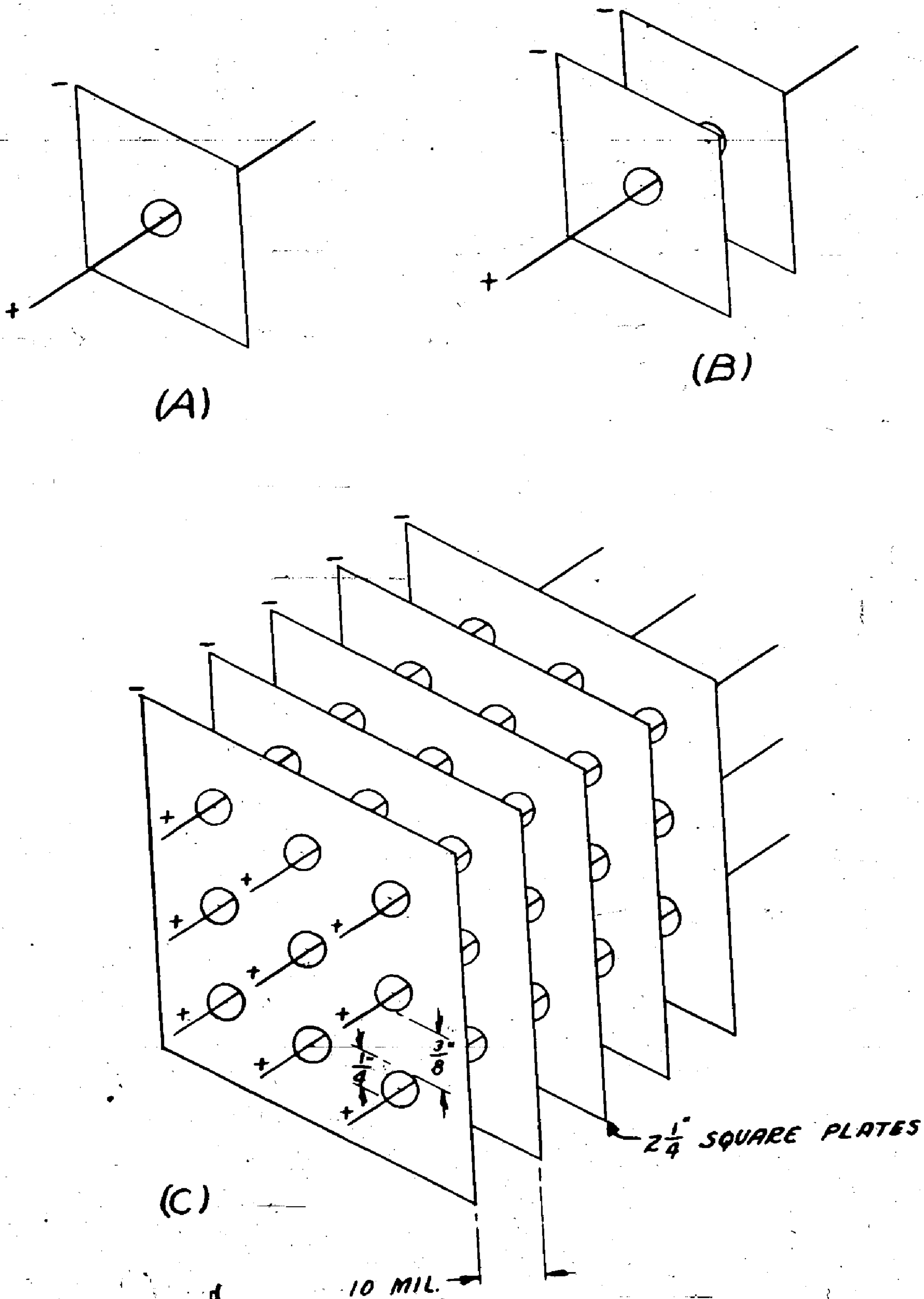


FIG. 27

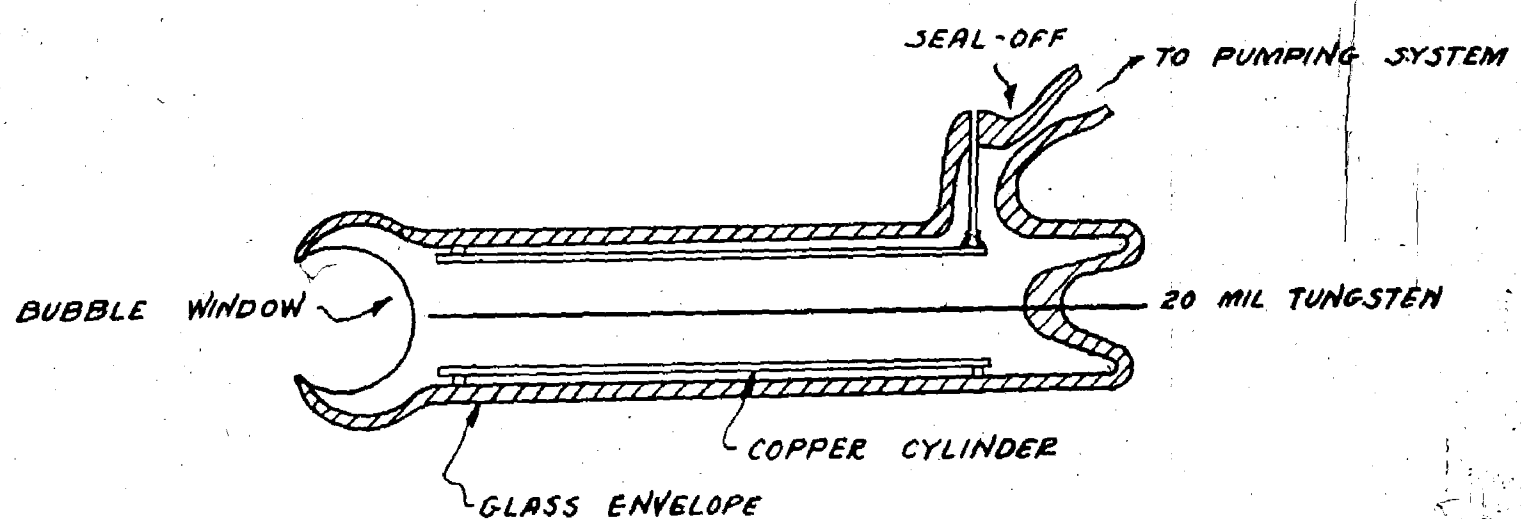

SEAL-OFF
TO PUMPING SYSTEM
BUBBLE WINDOW
20 MIL TUNGSTEN
COPPER CYLINDER
GLASS ENVELOPE

FIG. 28

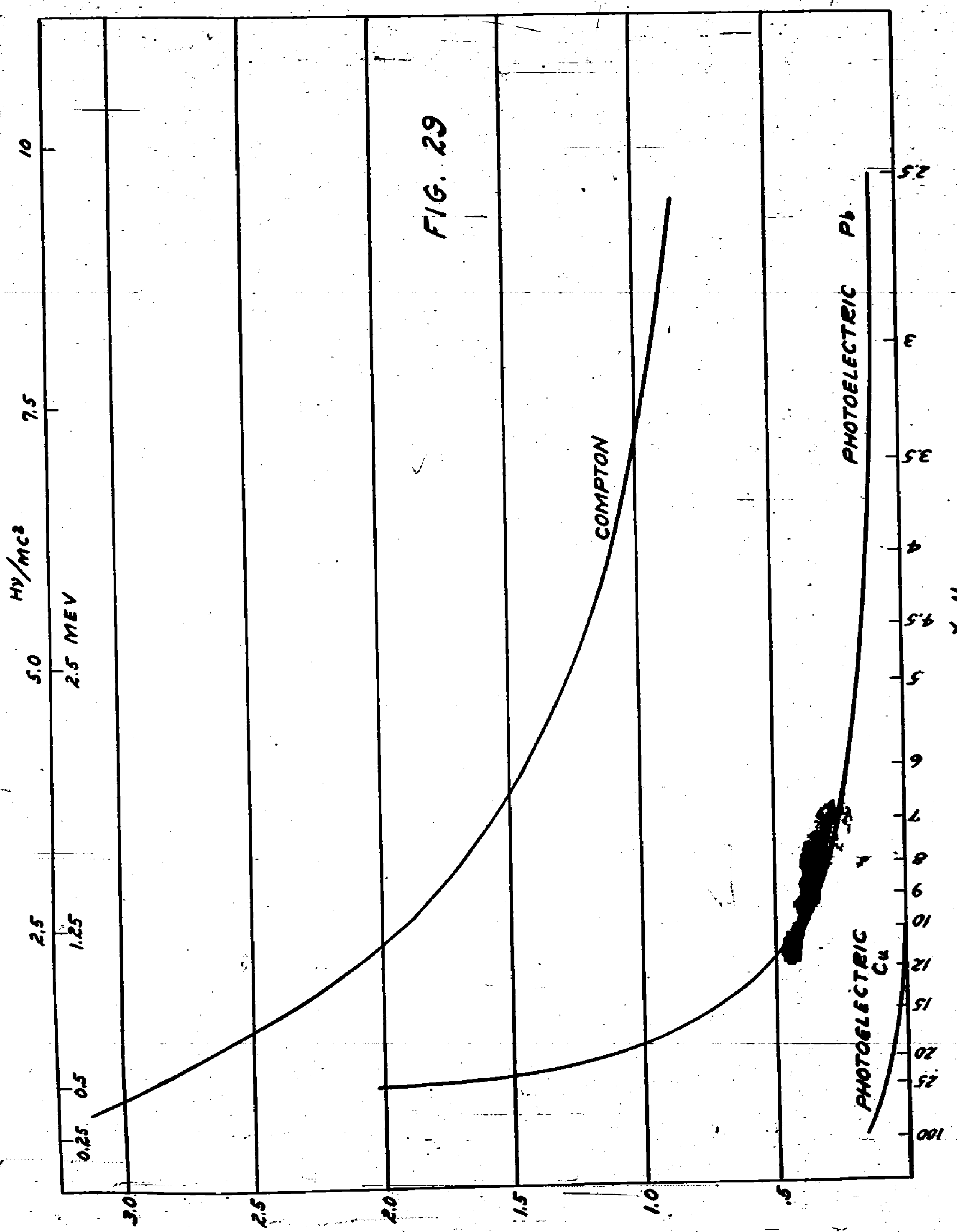


FIG. 29
Hγ/MC²
2.5 MEV
10
7.5
5.0
2.5
1.25
0.5
0.25
3.0
2.5
2.0
1.5
1.0
.5
COMPTON
PHOTOELECTRIC Pb
PHOTOELECTRIC Cu
X. U.
2.5
3
3.5
4
4.5
5
6
7
8
9
10
12
15
20
25
100

PLATE 25

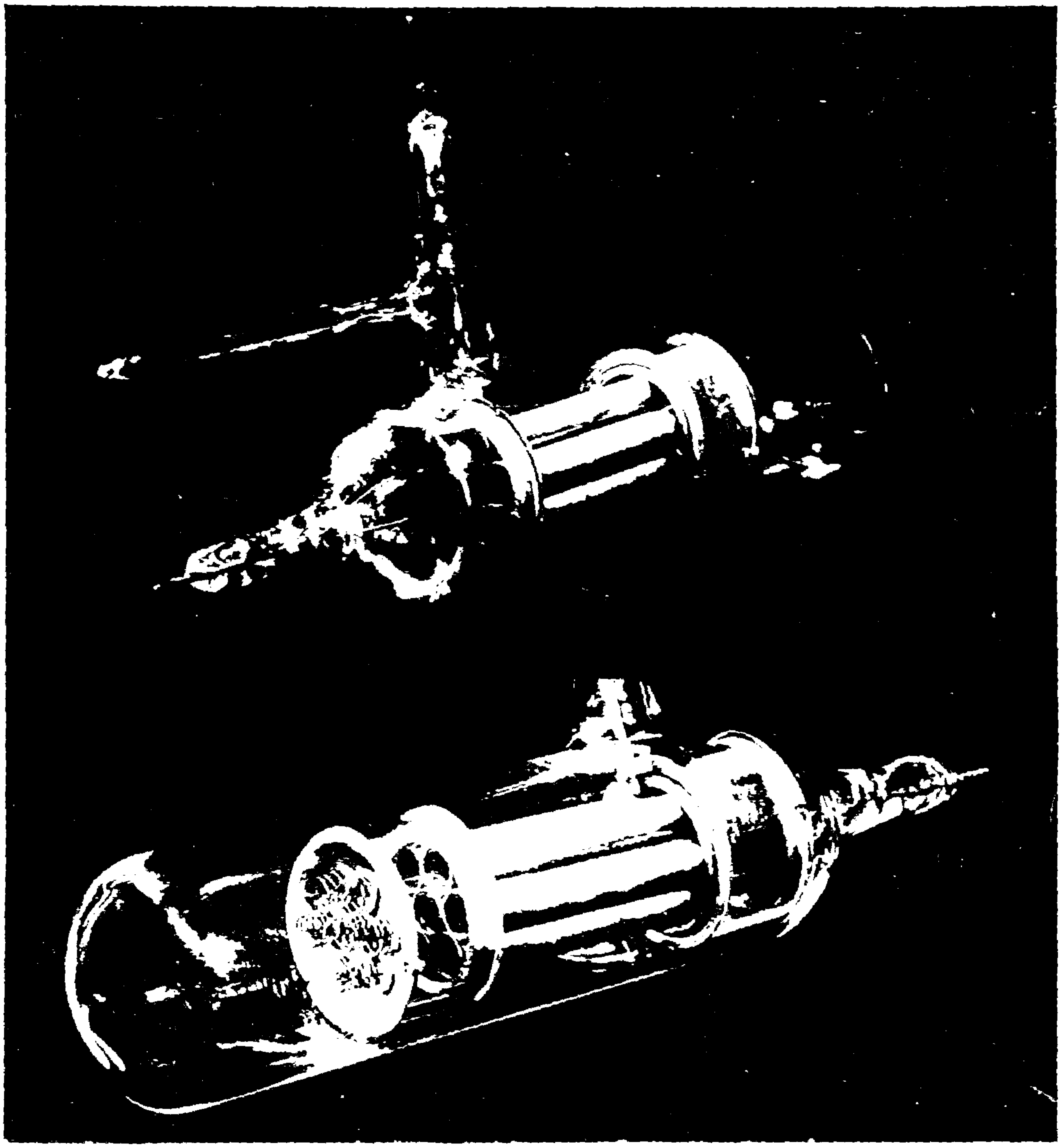


PLATE 26

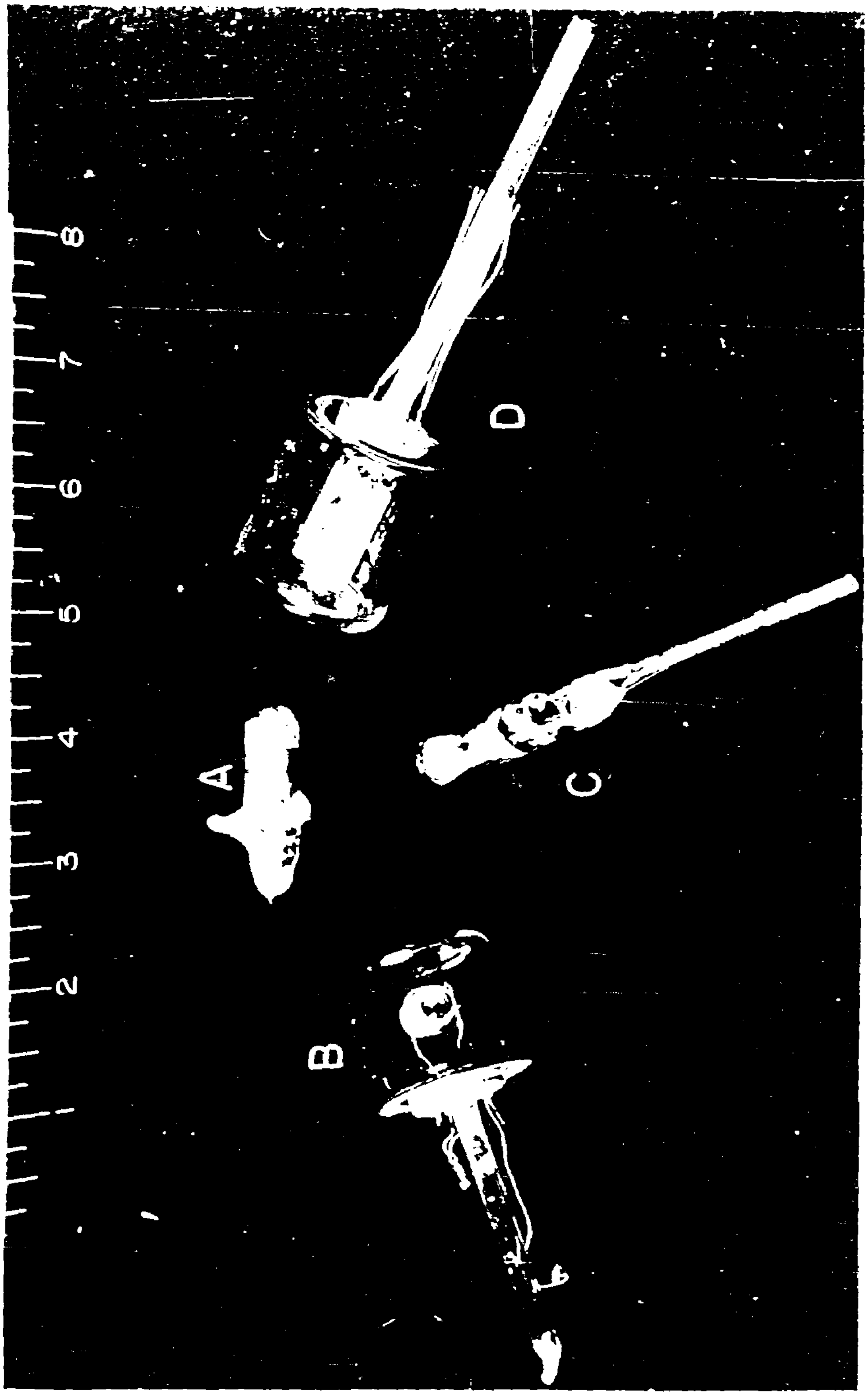


PLATE 27

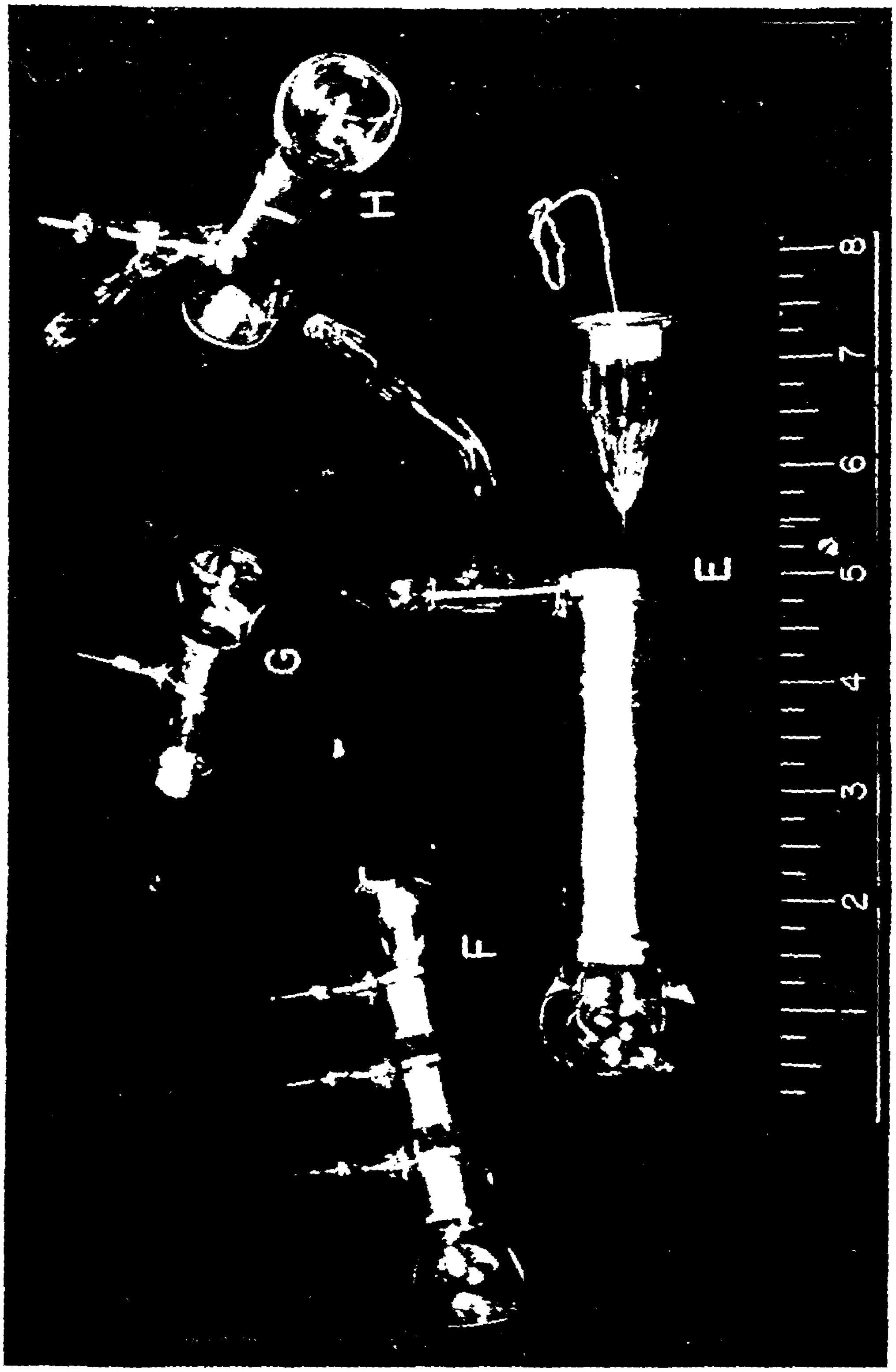


PLATE 28

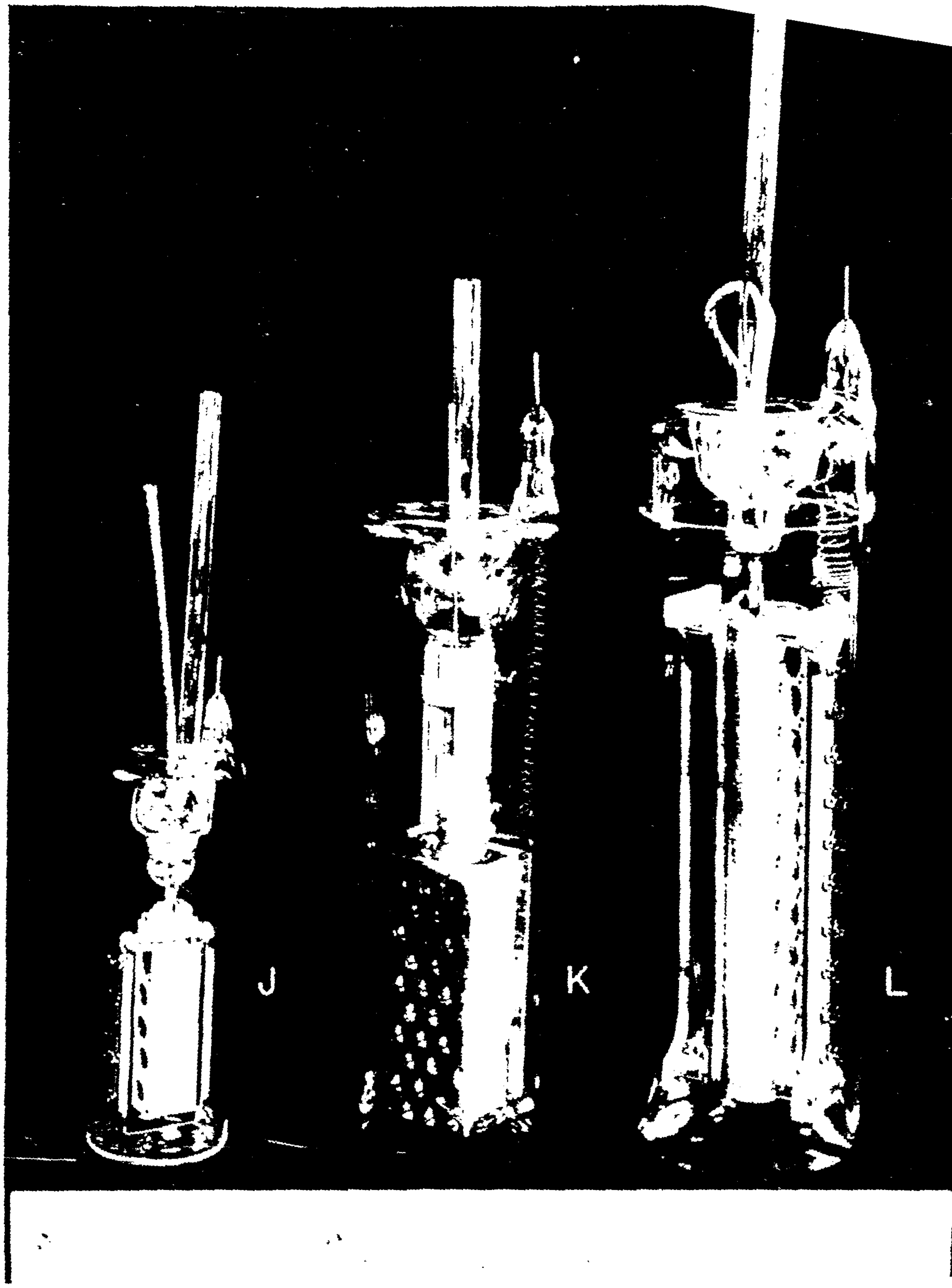
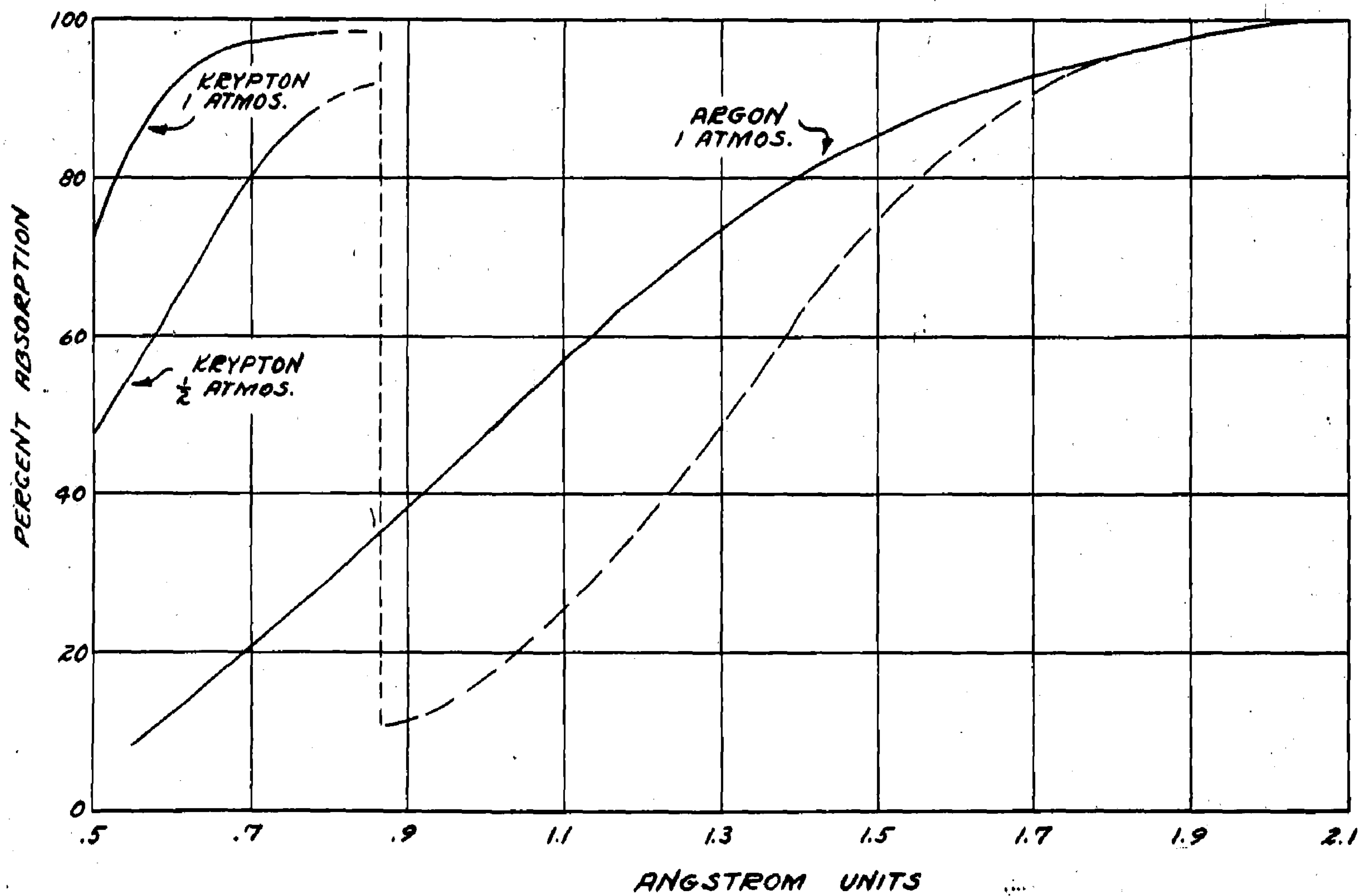
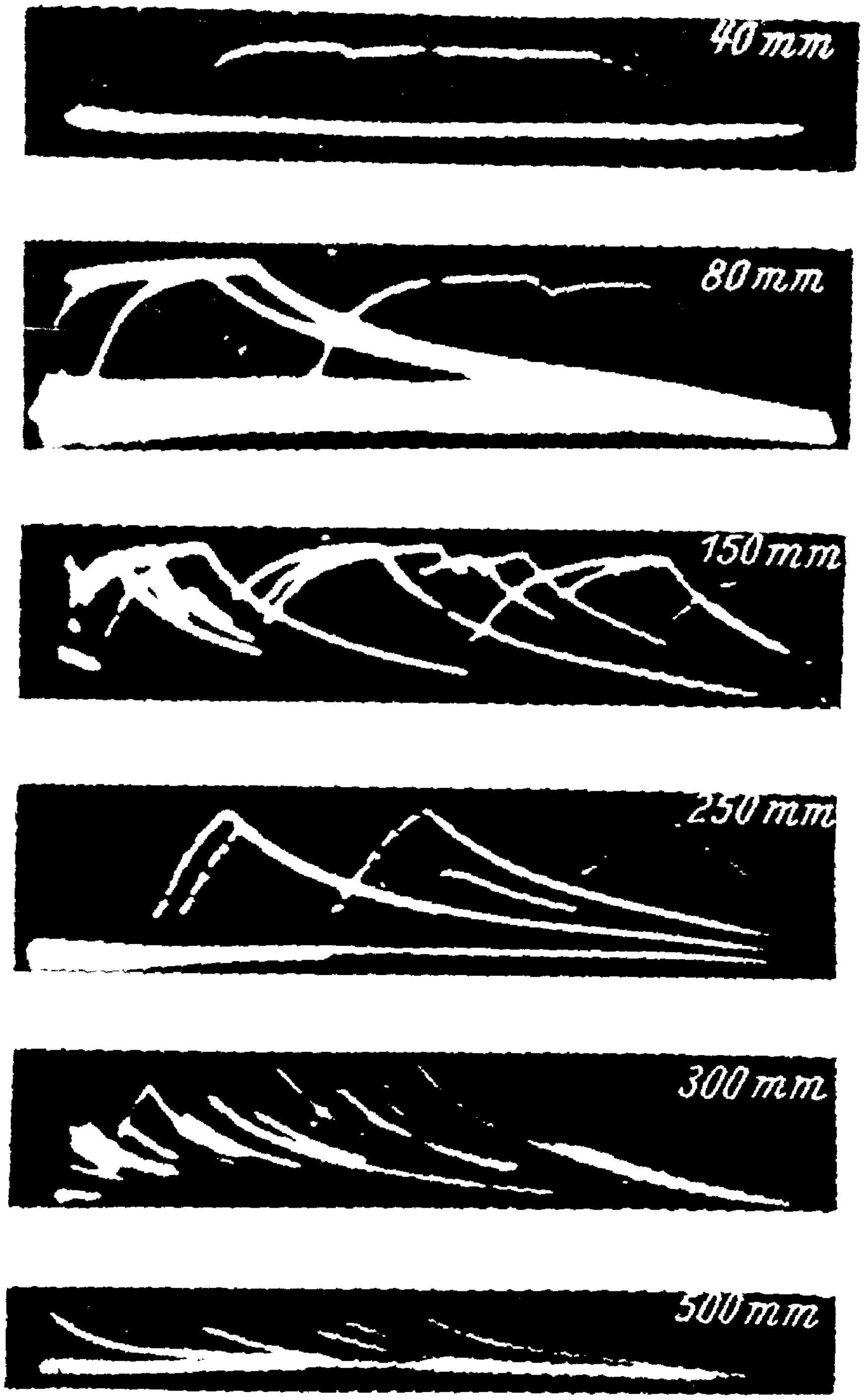


PLATE 29

ABSORPTION OF X-RAYS IN A
COUNTER 10 CM. LONG.

FIG. 30





EFFECT OF PRESSURE ON PULSE SHAPE
IN PURE ARGON COUNTER.

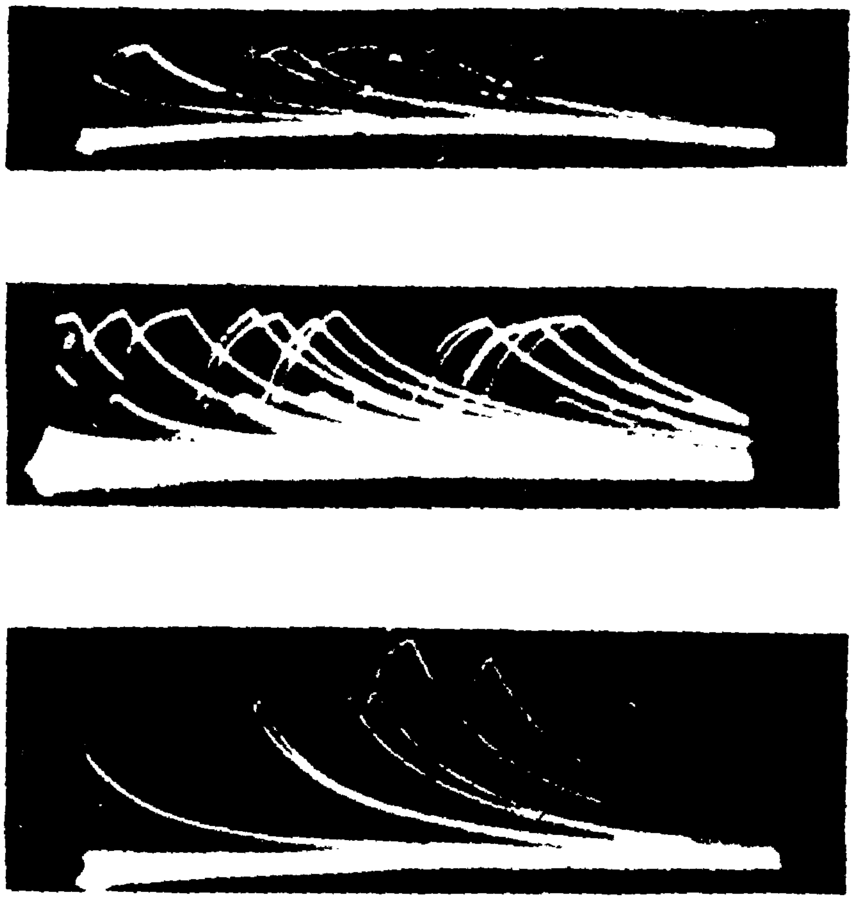
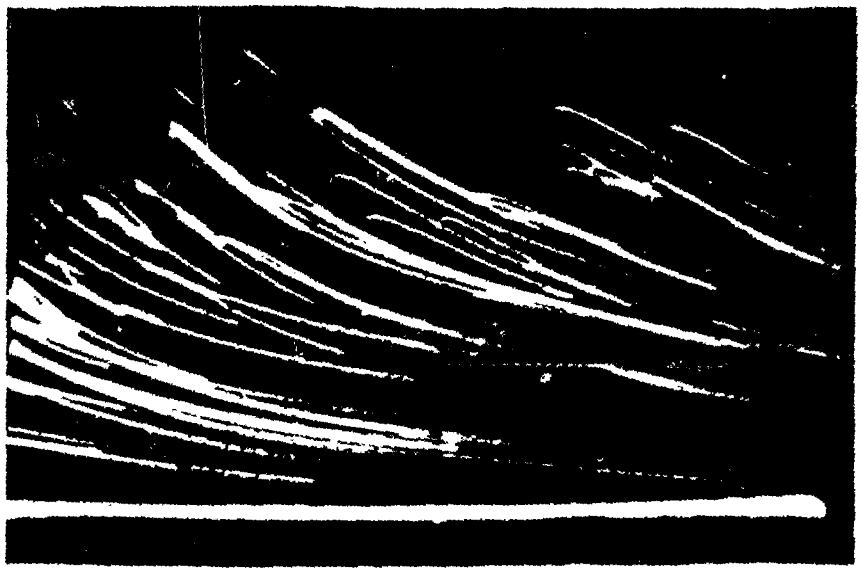


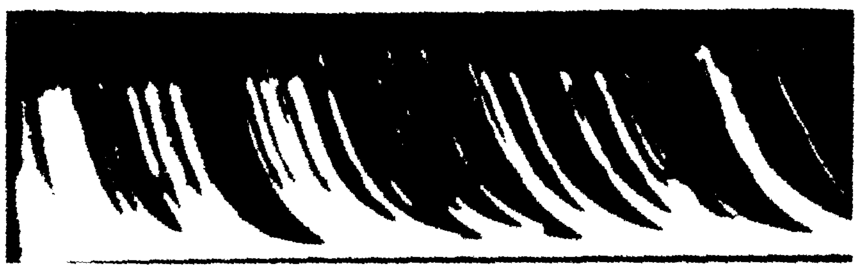
FIG. 31 – EFFECT OF ALCOHOL PRESSURE ON PULSE SHAPE

FIG. 32. – SHARP MULTIPLE PULSES OBSERVED NEAR UPPER LIMIT OF PLATEAU.

300 MEGOHMS



10 MEGOHMS



1 MEGOHM

EFFECT OF SERIES LEAK RESISTANCE ON PULSE SHAPE

PLATE 33

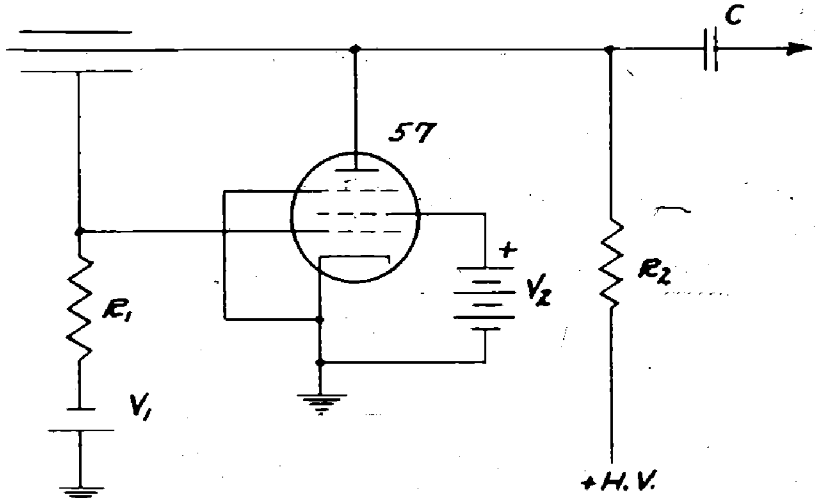
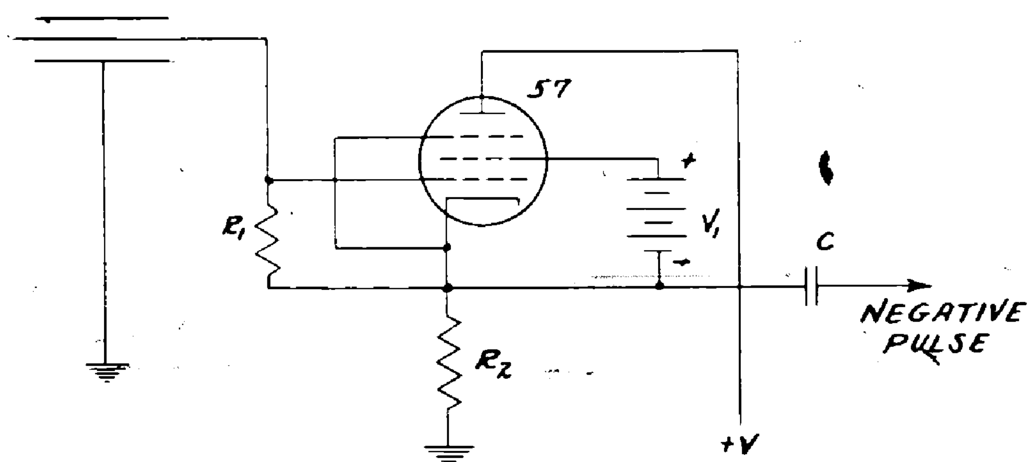


FIG. 33



R_1 = 5 MEGOHMS
R_2 = 1 MEGOHM
V_1 = 45 VOLTS
V = COUNTER THRESHOLD PLUS 100 V.
C = 50 TO 100 $\mu\mu f$

FIG. 34

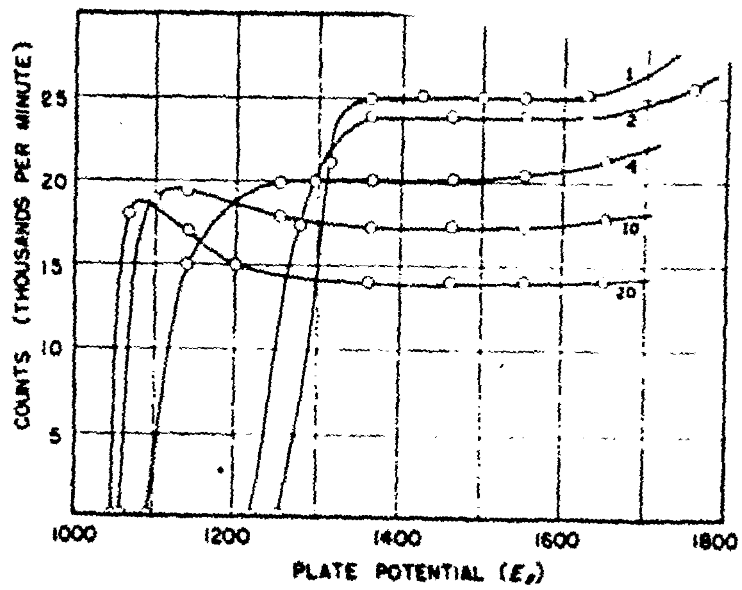


FIG. 35

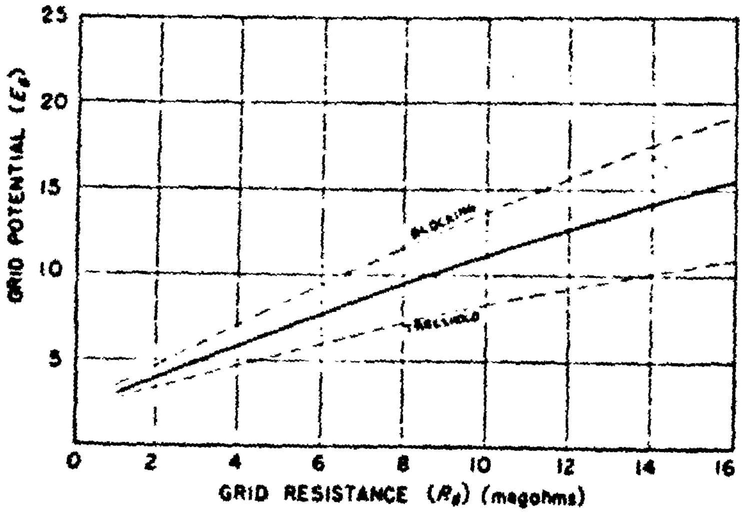


FIG. 36

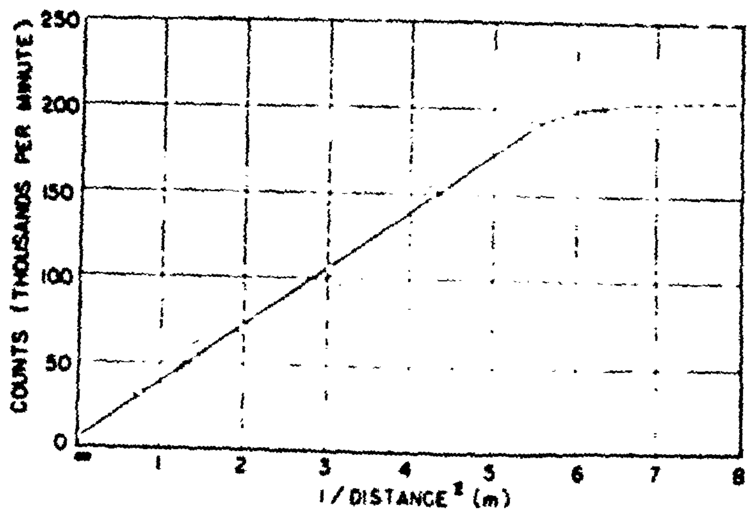


FIG. 37

PLATE

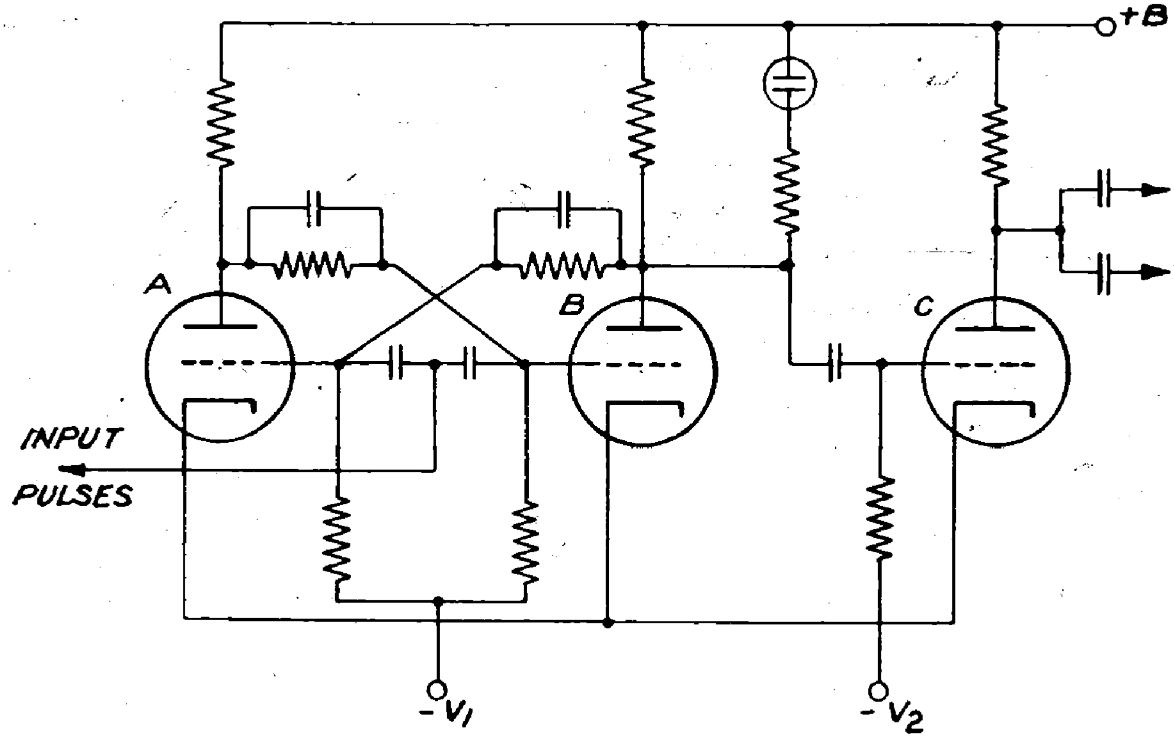

+B
A
B
C
INPUT
PULSES
-V1
-V2

FIG. 38

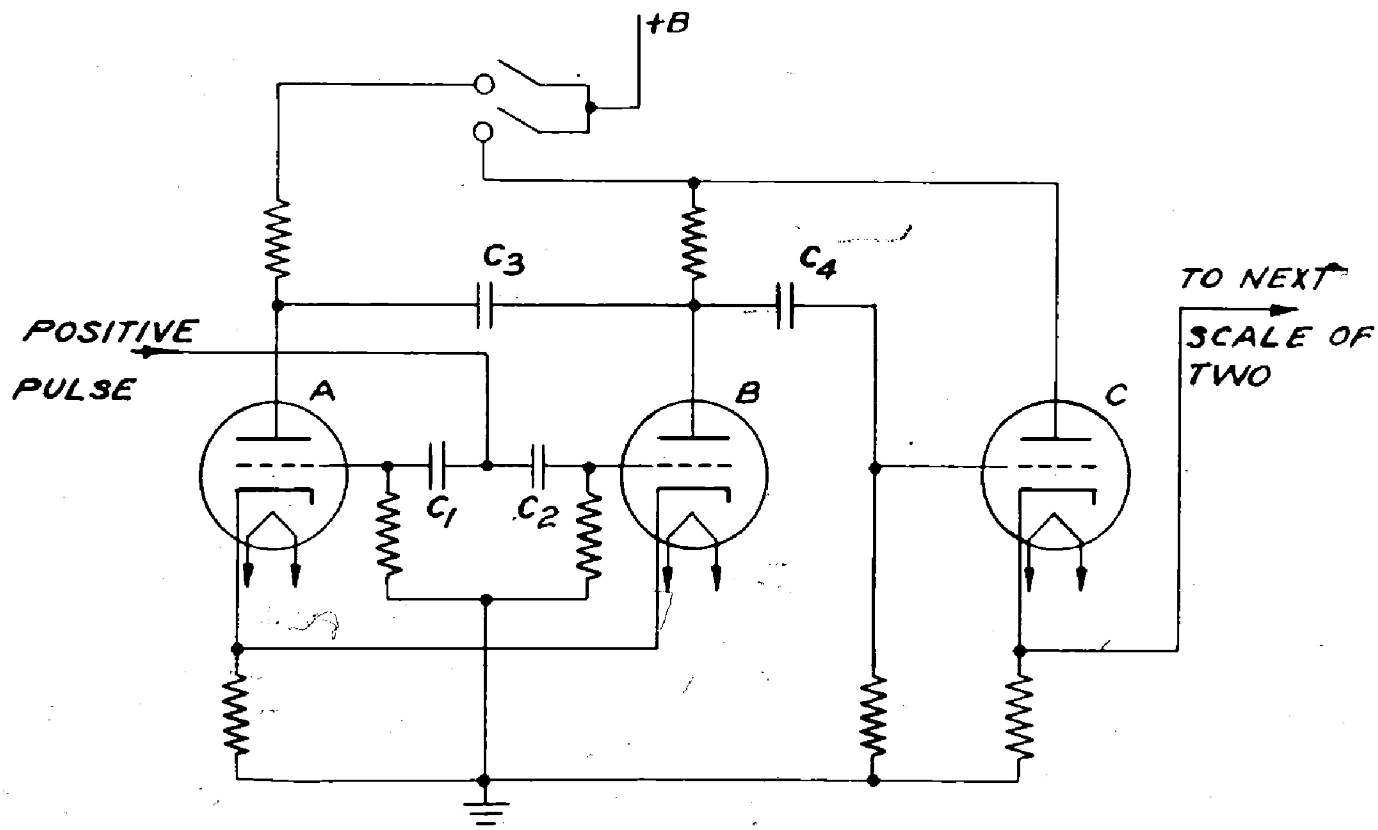

+B
C3
C4
TO NEXT
SCALE OF
TWO
POSITIVE
PULSE
A
B
C
C1
C2

FIG. 39

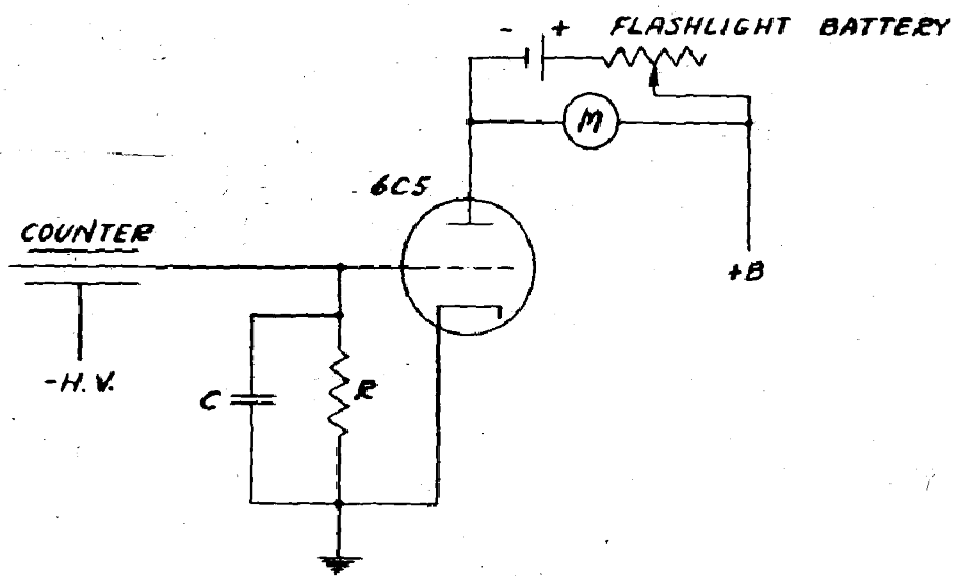

- +
FLASHLIGHT BATTERY
M
6C5
COUNTER
+B
-H.V.
C
R

FIG. 40

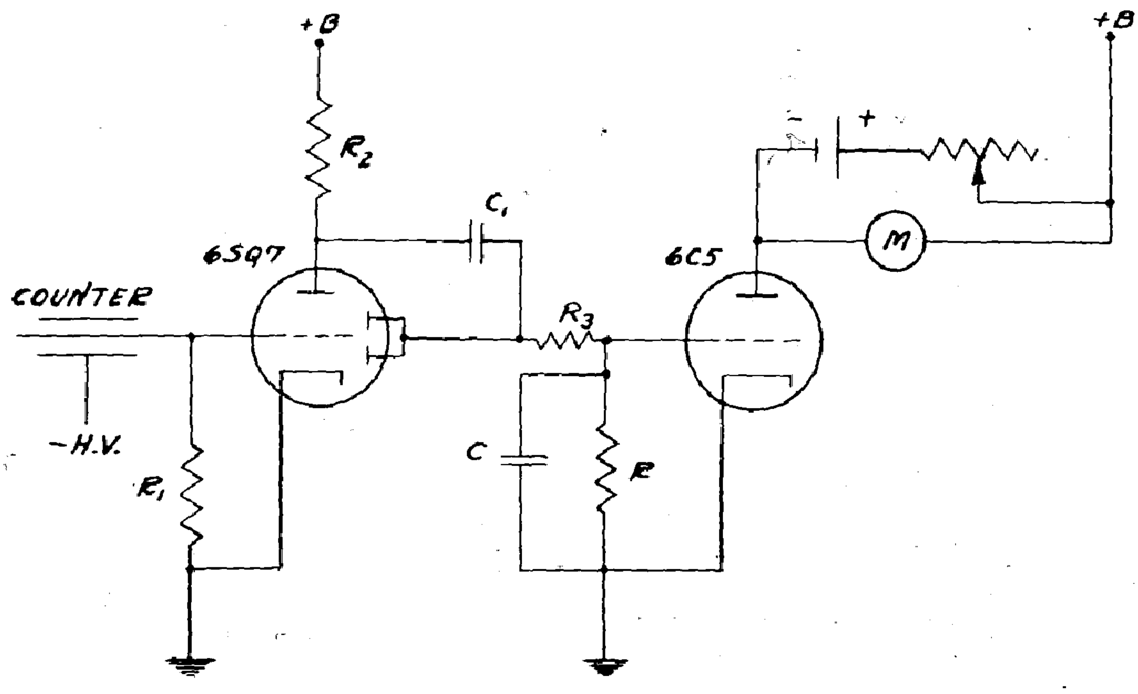
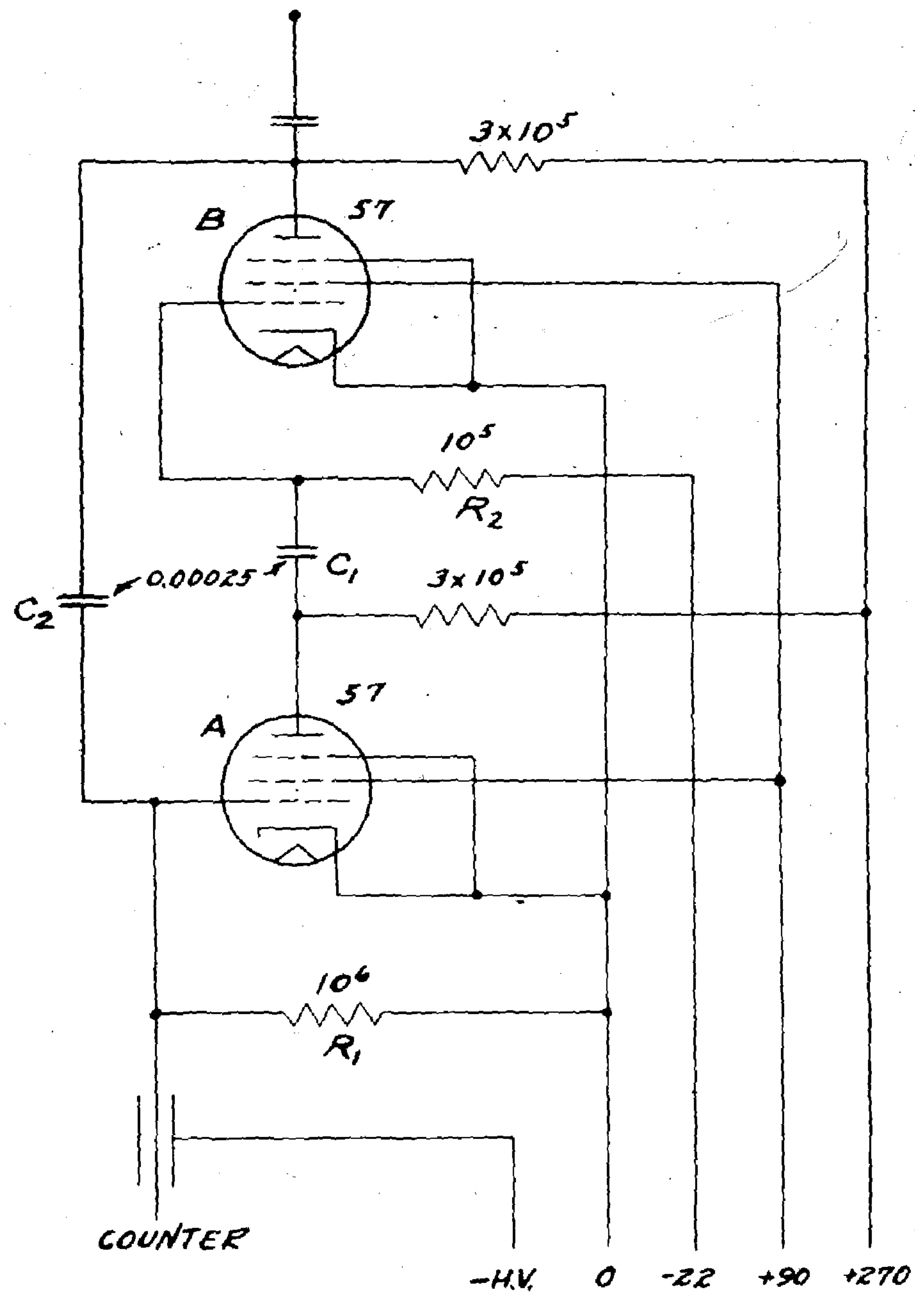
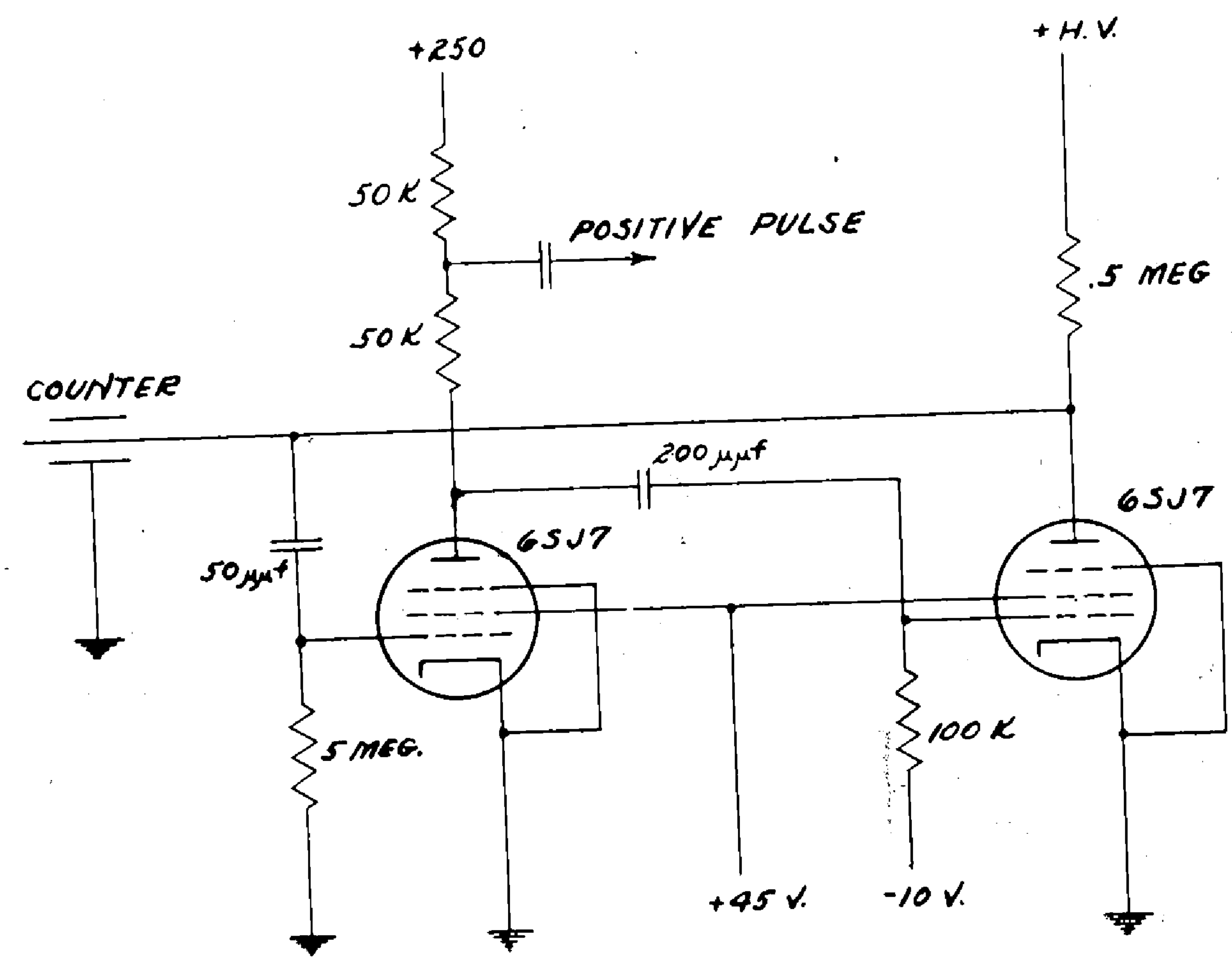

+B
+B
- +
R_2
C_1
M
6SQ7
6C5
COUNTER
R_3
-H.V.
R_1
C
R

FIG. 41



MULTIVIBRATOR QUENCHING CIRCUIT

FIG. 42



MULTIVIBRATOR QUENCHING CIRCUIT

FIG. 43

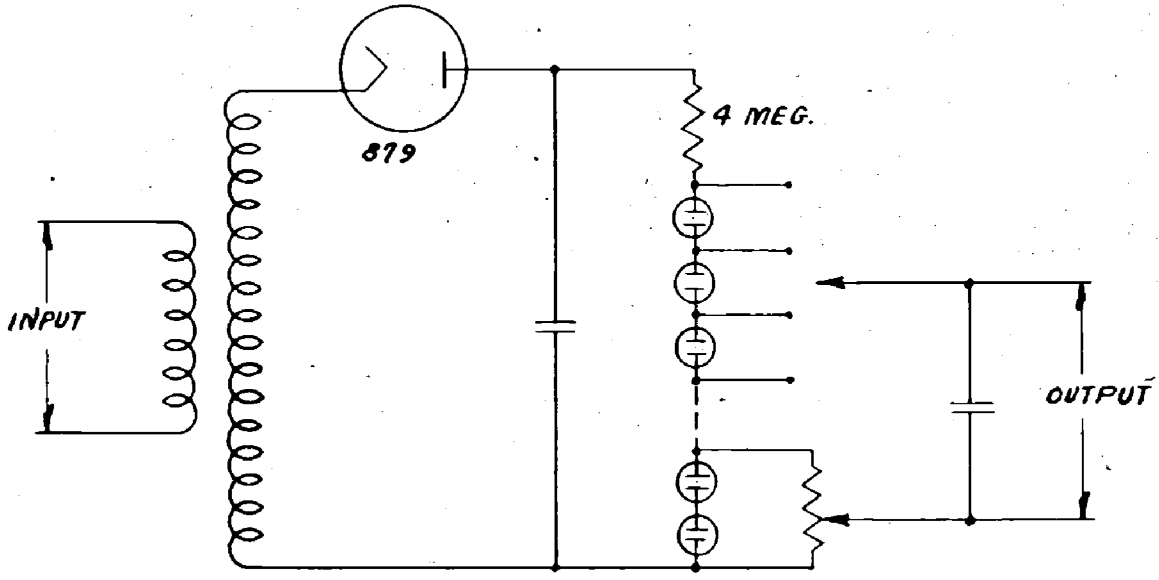

879
4 MEG.
INPUT
OUTPUT

FIG. 44

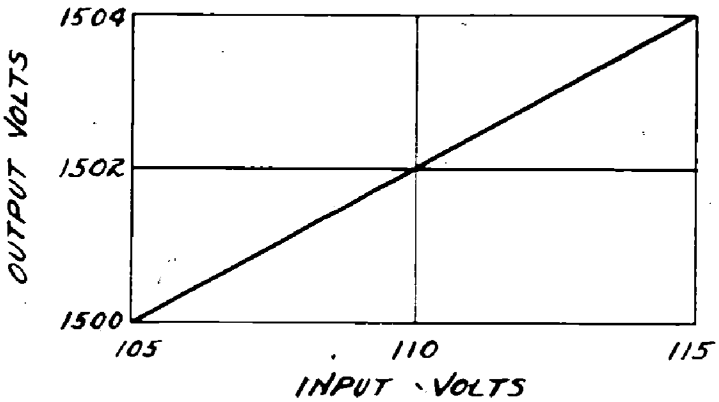

1504
1502
1500
OUTPUT VOLTS
105
110
115
INPUT VOLTS

FIG. 45

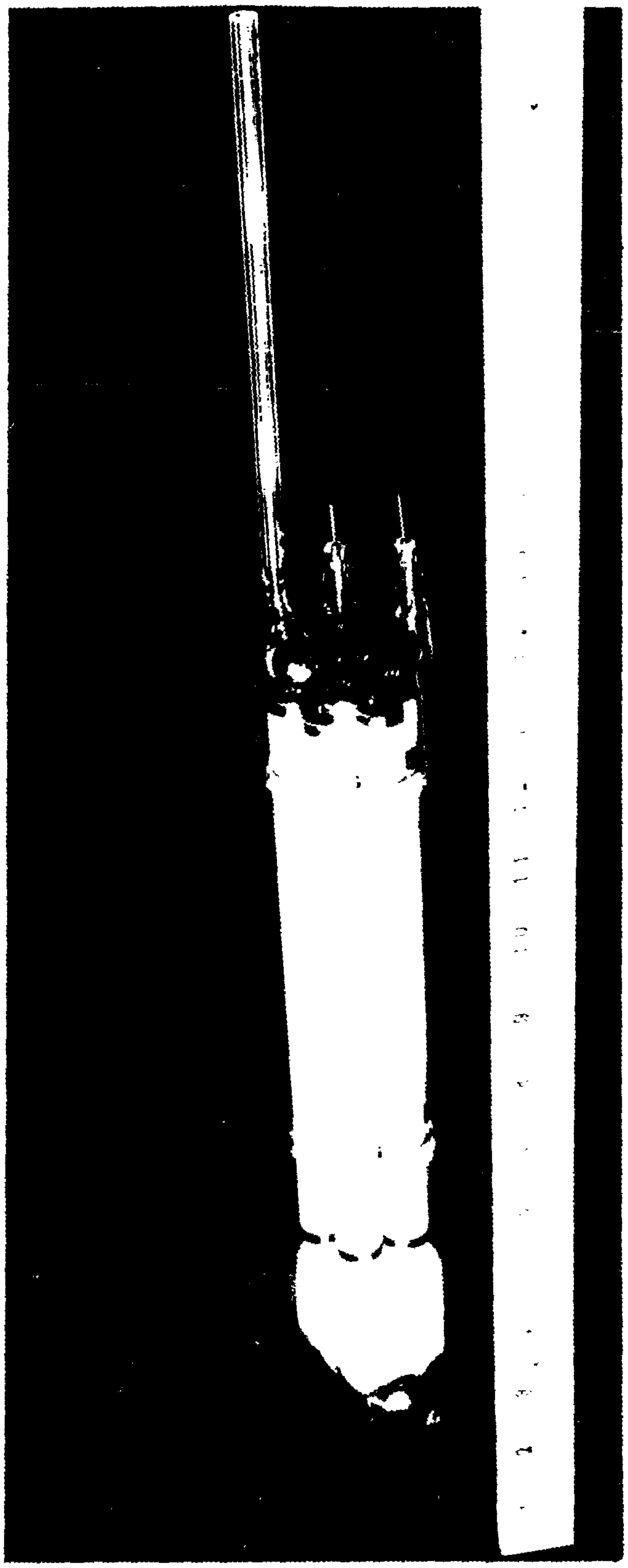


PLATE 41

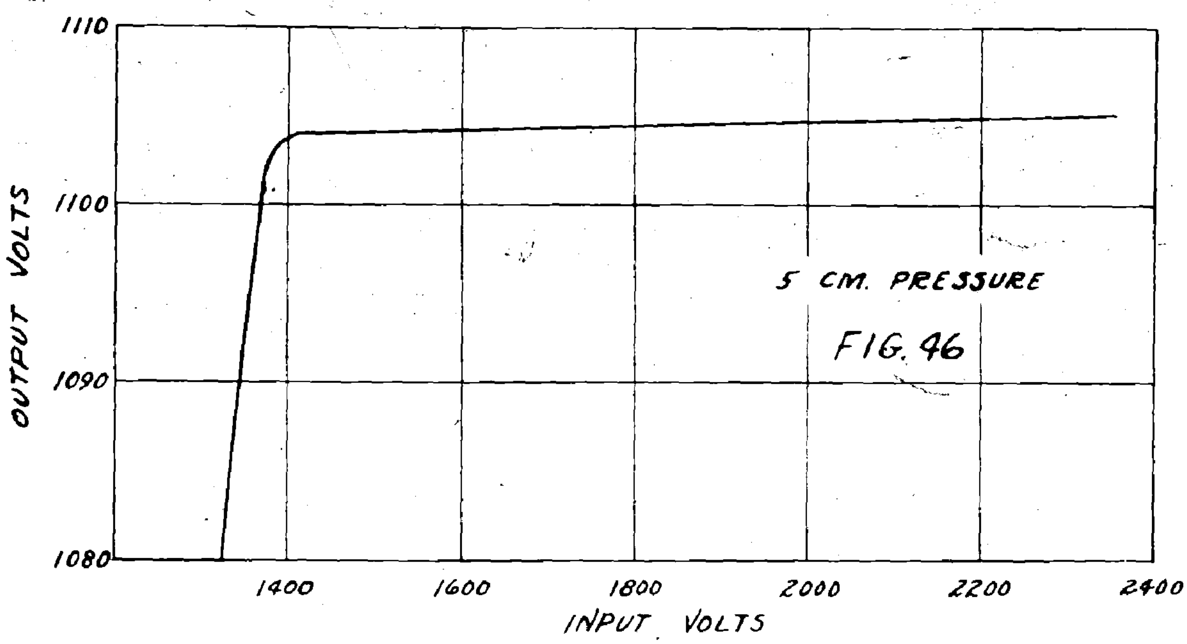

1110
1100
1090
1080
OUTPUT VOLTS
1400
1600
1800
2000
2200
2400
INPUT VOLTS
5 CM. PRESSURE

FIG. 46

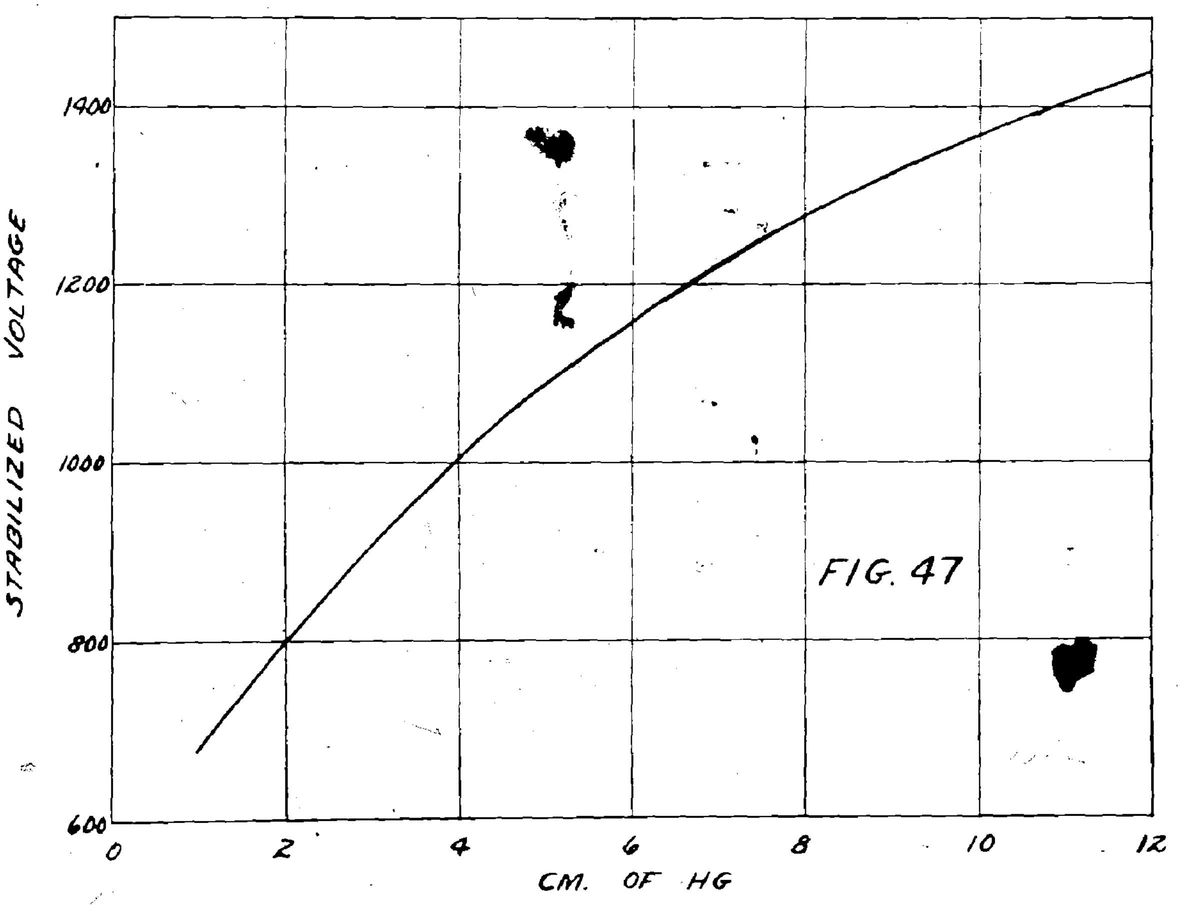
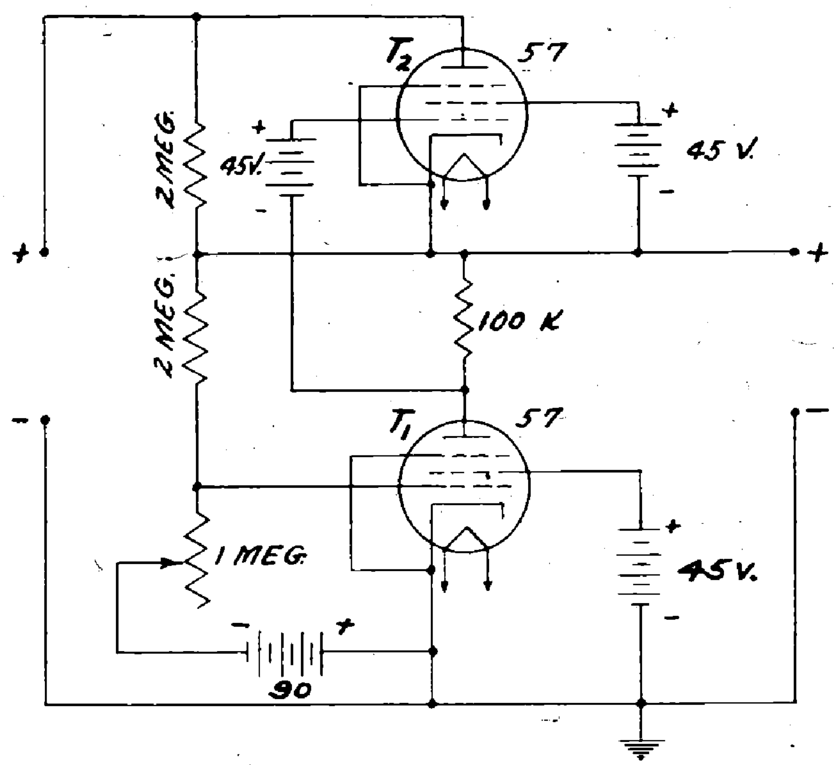
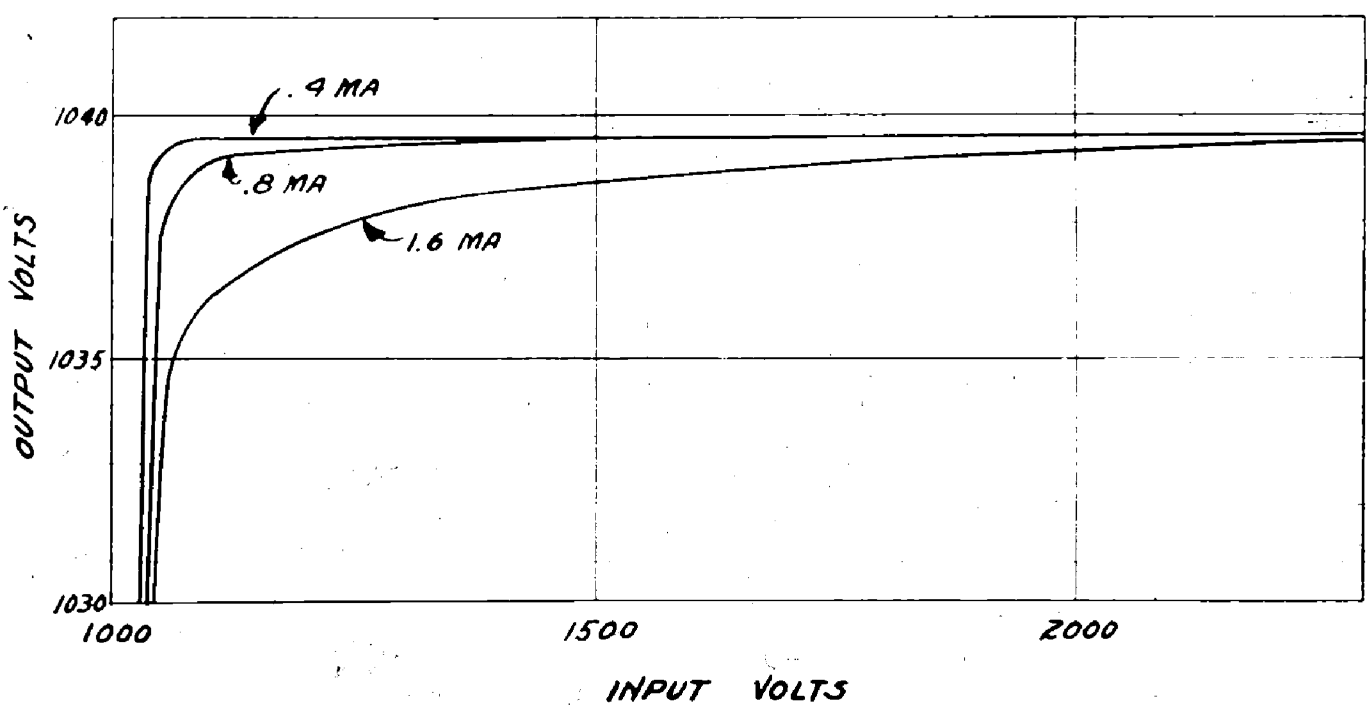

1400
1200
1000
800
600
STABILIZED VOLTAGE
0
2
4
6
8
10
12
CM. OF HG

FIG. 47



T2
57
2 MEG.
45V.
45 V.
+
-
2 MEG.
100 K
T1
57
1 MEG.
90
45 V.

FIG. 48



.4 MA
.8 MA
1.6 MA
OUTPUT VOLTS
1040
1035
1030
1000
1500
2000
INPUT VOLTS

FIG. 49

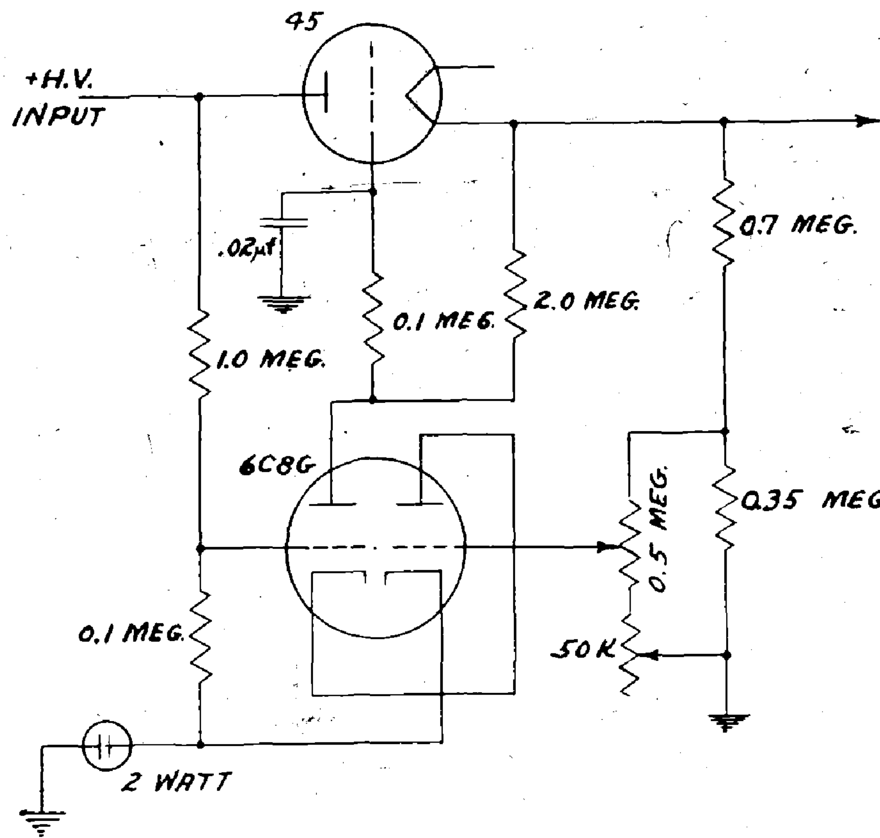

45
+H.V.
INPUT
.02µf
1.0 MEG.
0.1 MEG.
2.0 MEG.
0.7 MEG.
6C8G
0.5 MEG.
0.35 MEG.
0.1 MEG.
50 K
2 WATT

FIG. 50

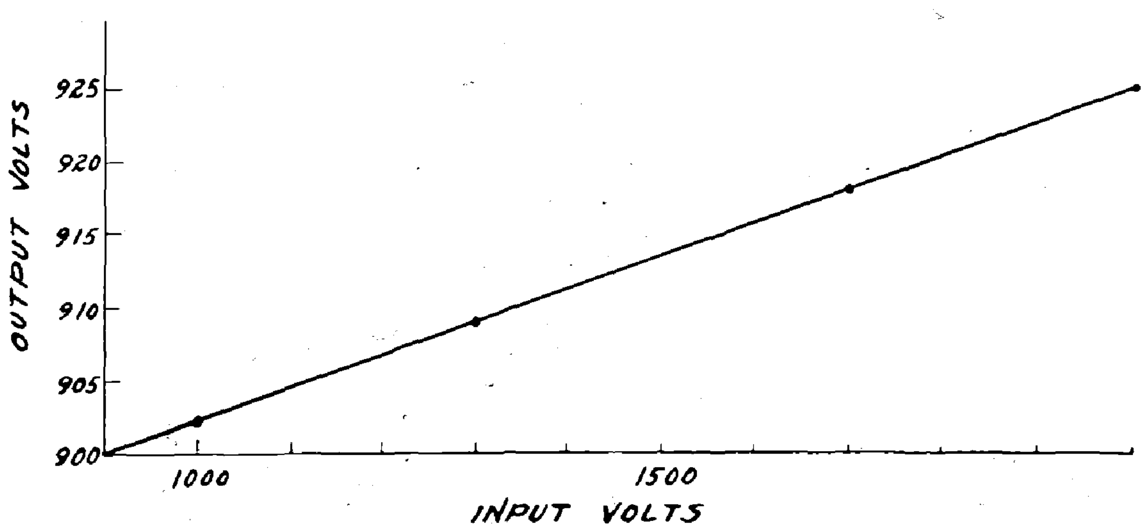

OUTPUT VOLTS
925
920
915
910
905
900
1000
1500
INPUT VOLTS

FIG. 51

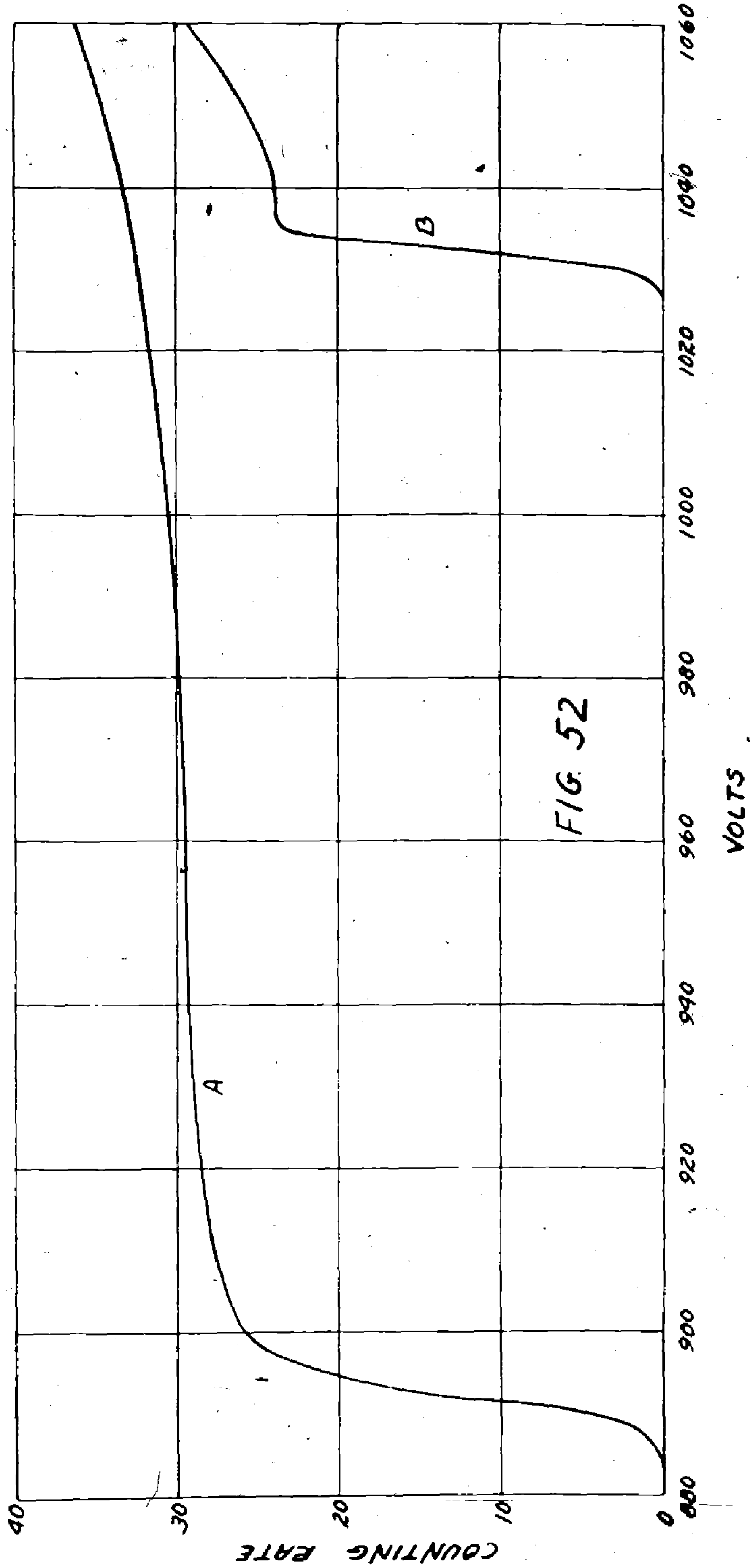


FIG 52

PLATE 45

REEL – C

169[illegible]

A.T.I.

3820[illegible]

TITLE: Geiger Counter Technique	AD-B811200
	ATI- 38203
	REVISION (None)
AUTHOR(S): Friedman, Herbert	
ORIGINATING AGENCY: Office of Naval Research, Naval Research Lab., Anacostia Station, Washington, D. C.	ORIG. AGENCY NO. N→ NRL-M-1800
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DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Jan '42	Unclass.	U.S.	Eng.	68	photos, diagrs, graphs

ABSTRACT:

A comprehensive investigation of counters and counting circuits was initiated for the purpose of developing counters with ultimate sensitivity and capable of meeting the requirements of high speed counting. The counting process is discussed, the construction and preparation of counters are explained, and methods of obtaining high resolution and sensitivity are given. A description is given of the most important circuits for counting, and the conditions under which they are employed. The investigation resulted in new designs for gamma ray and hard X-ray counters having quantum counting effeciencies up to 50%. Soft X-ray counting efficiencies of 100% were obtained. A new principle of counter construction resulted in resolving powers up to 100,000 random counts per second, as compared with the previous maximum of 3000.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

DIVISION: Atomic Energy (48)	SUBJECT HEADINGS: Geiger counters (45000)
SECTION: Instruments and Techniques (6)	new 20 / 30
ATI SHEET NO.: R-48-6-22	dec 5 / 3-5 251950

UNITED STATES GOVERNMENT

memorandum

DATE: Ser 059
28 Sep 98

REPLY TO ATTN OF: Code 7600

SUBJECT: REVIEW OF "GEIGER COUNTER" REPORTS

TO: Codes 5227
1221.1 Cu 9/30/98

1. I have reviewed five unclassified NRL reports entitled, "Geiger Counter Technique (M-*1800)," "Geiger Counter Technique for High Counting Rates (H-2758*)," "Geiger Counter Tubes (ADB196664)," "Low Voltage Self-Quenching Geiger Counters (N-3189*)," and "Sensitive Geiger-Muller Counters for Detection of Gamma Rays (M-1886).")
NO AD #

2. I recommend that the "limited distribution" statements be removed from each report and be replaced with "unlimited distribution." Thank you.

HERBERT GURSKY
Superintendent
Space Science Division

*AD-B811200
AD-B217749
AD-B218681
AD-B196664

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GSA FPMR (41 CFR) 101-11.6
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